Which manufacturing industries and sectors are most vulnerable to Brexit?

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Which Manufacturing Industries and Sectors Are Most Vulnerable to Brexit?

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Abstract

When the UK leaves the EU, trade arrangements between the UK and EU will change. Most of the options for future UK-EU relationships currently under discussion imply increased trade barriers, which will reduce trade and also have effects on output and prices. In this paper, we use a multi-market partial equilibrium model to analyse the vulnerability of 122 manufacturing industries to Brexit. In all five Brexit scenarios we model, there is an overall reduction in UK manufacturing output. Output grows in some industries but at the expense of higher consumer and intermediate goods prices. High tech and medium-high tech sectors are more at risk of a decline in domestic production than lower tech sectors. In most areas of the country, demand for high-skilled workers falls more than for medium and low-skilled workers.

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1. Introduction

When the UK leaves the EU, trade arrangements between the UK and EU will change, but the form of the new arrangements was still far from clear even towards the end of 2018. Several options were under discussion, ranging from the UK having some form of customs union with the EU and retaining membership of the Single Market, to the UK trading on WTO terms with the EU. Each of these options entails increased trade barriers. Higher barriers will inevitably reduce trade and also have effects on output and prices. To the extent that the UK manages to sign new free trade agreements with third countries, some of these effects may be mitigated.

The effects of Brexit will vary across industries and sectors. The importance of the EU either as a destination market for UK producers or as a supplier in the UK market differs between industries; as do the level of tariff and non-tariff barriers. The aim of this paper is to contribute to the existing empirical literature on the impact of Brexit through the use of a multi-market partial equilibrium (PE) model applied to UK manufacturing industries and sectors.

Most of the existing formal empirical work is based on the application either of computable general equilibrium (CGE) models (Dhingra et al., 2017; Ciuriak et al., 2015; Kierzenkowski et al., 2016; HM Treasury, 2016) or of gravity models (Ebell and Warren, 2016).[1] The advantage of a PE model is that it enables the effects of policy to be modelled at a much finer level of sectoral disaggregation than is possible within a CGE framework; with much more up-to-date trade data. For example, the UK Government's internal cross-Whitehall model uses a Global Trade Analysis Project (GTAP) dataset with up to 57 sectors, within which (in the limited results which have been released) there appear to be nine manufacturing sectors. In contrast, we have 122 manufacturing industries, based on the 4-digit classes of ISIC Revision 4, and the data are based on 2016 trade flows. This greater level of disaggregation matters in several respects.

First, and most obviously, it allows for a much more detailed examination of the possible impacts on prices, output and trade in specific industries. We can model more accurately the variation in trade policy (i.e., tariffs and non-tariff barriers) across different industries, and also across different trading partners.

Second, we show that, at least for some sectors, aggregation makes a difference: the aggregated results of analysis conducted at a disaggregated level can be significantly different from the results of the same analysis done at the aggregated level.

Third, the detailed level of aggregation we work with makes it possible to consider the impact across industries according to their underlying characteristics, for example their technological intensity.

Finally, as well as specific industries or sectors, we can examine the impact on different areas of the UK, and the impact on different categories of labour. By using information available on output and employment at the sub-national level, we can provide a much more accurate assessment of the possible impact of different Brexit scenarios on geographic areas and labour markets than can be done with a more aggregate CGE modelling framework.

A PE modelling approach has disadvantages as well as advantages. CGE models take account of both product and factor market linkages, which our model does not. These linkages can show how changes in employment in some sectors might affect other sectors through their impact on wages; or how changes in UK agriculture might affect food manufacturing, or changes in the motor vehicle components industry could affect the car industry. However, the fact that data on input-output linkages or on skill-intensity are available only at a fairly aggregated level limits the degree of disaggregation possible in a CGE model.

The PE modelling results we present here should therefore be seen as illustrating the direct, first-order impacts of policy. The longer-run implications will depend on how quickly and how easily businesses can adjust to the new economic landscape after Brexit.

The rest of this paper is organised as follows. In the next section, we discuss the policy context. In Section 3, we review selected recent analytical studies of the impact of Brexit to date, and in Section 4, we discuss the modelling approach adopted in our work and our data sources. Sections 5 and 6, respectively, look at the impact of five Brexit scenarios on different manufacturing sectors, and on labour markets across different geographic areas. Section 7 provides a summary of 'average impact' results depending on the modelling assumptions and the version of the partial equilibrium model used.

[1] The report by Tetlow and Stojanovic (2018) provides a summary of the recent 14 studies on the long-term impact of Brexit, and highlights the differences in the assumptions used in economic models that drive the large variation in the respective predictions of the long-term impact.

2. The Policy Context

Because the UK is in the EU Customs Union (CU) and the European Single Market (SM), all trade between the United Kingdom and the European Union is tariff-free and subject to low non-tariff barriers. Membership of the CU gives the UK tariff-free market access for all exports to and imports from the EU, with a common external tariff (CET) for imports from third countries. The common external trade policy eliminates the need for rules-of-origin checks at intra-EU borders because the regime for imports from outside the customs union is the same at all points of entry. Membership of the SM means that a product placed for sale in any given EU country can be sold in any other EU country without any further need to prove that EU standards have been met. The absence of tariffs, origin checks and regulatory checks at intra-EU borders results in shorter transport times and lower trade costs.

These low trade costs, coupled with geographic proximity, explain why the EU is the UK's largest trading partner. In 2017, 49% of total UK exports and 54% of total UK imports were with the EU. A further 15% of exports and 14% of imports were with the nearly 70 countries with whom the EU (including therefore the UK) has free trade agreements (FTAs), and over 5% of both imports and exports are with the European Free Trade Association (EFTA) countries (Iceland, Liechtenstein, Norway and Switzerland).[2]

Trade in goods is still the largest part of trade with the EU (and other partner countries). In 2016, goods exports from the UK to the EU were worth £145 billion, with services exports £90 billion. On the import side, trade was even more weighted towards goods: UK imports of goods from the EU were worth £242 billion as compared to £76 billion of services imports. Overall, in 2016, goods exports accounted for 55% of UK total exports, and goods imports accounted for 74%.[3]

Brexit is likely to lead to some reorientation of the UK's trade, as well as some change in its composition. The policy alternatives for the future trade relationship with the EU that were still being discussed late in 2018 included: a full or partial customs union with the EU; membership of the European Economic Area (EEA) which would mean the UK remaining in the SM; a free trade agreement (FTA) with or without Single Market access to the EU; or trading on WTO terms. As well as negotiating the terms of future trade with the EU, the UK also needs to establish the basis upon which it will trade with the EU-FTA countries. The UK Government has repeatedly stated that it would like to roll over ('grandfather') these agreements.

Leaving the EU is therefore likely to increase the costs of trade between the UK, the EU and the current EU-FTA partner countries. If the UK does not agree a new FTA with the EU and does not grandfather the existing 37 FTAs, tariffs will be reintroduced on trade between the UK and these countries, and non-tariff barriers will increase. But even if the UK and the EU agree an FTA that covers all sectors and has zero tariffs on all goods,[4] and if the UK rolls over the existing FTAs, there will be additional costs associated with rules-of-origin compliance, if the UK is no longer in a CU. These extra barriers to trade flows imply that even the most ambitious UK-EU FTA will not replicate the levels of market access or keep trade costs as low as they are now (Lydgate and Winters, 2018). In all cases, Brexit is likely to affect trade flows between the UK, the EU and the EU-FTA partners.

Much has been made by some politicians and commentators of the opportunities the post-Brexit UK will have to make new FTAs with countries such as the US and India with whom the EU does not currently have FTAs. Any such agreements should reduce trade barriers and mitigate at least some of the effect of increases in trade barriers with the EU and with the existing EU-FTA partners, and we consider the extent to which agreements with third countries could offset the effects of withdrawal from the EU.

3. Literature Review

Most of the existing empirical literature concludes that Brexit, by making trade between UK and the EU more costly, will have negative economic consequences for the UK economy. Different approaches have been used to estimate these effects. Table 1 summarises the key features and results of some of this

[2] Source: UN Comtrade.

[3] Source: ONS Pink Book 2017. In 2016, the value of UK's goods exports stood at £302 billion, increasing from £289 billion in 2015. Imports of goods were worth £437 billion, up from £407 billion in 2015.

[4] Statement by President Donald Tusk (7 March 2018) on draft guidelines on the framework for the future relationship with the UK explicitly named trade agreement between the UK and the EU covering all sectors and with zero tariffs on goods as an official EU negotiating position. See: http://www.consilium.europa.eu/en/press/press-releases/2018/03/07/statement-by-president-donald-tusk-on-the-draft-guidelines-on-the-framework-for-the-future-relationship-with-the-uk/.

literature.

Table 1: Selected analytical studies of Brexit to date: summary of methodologies used and main findings

Study	Variable measured	*Soft Brexit*	*FTA*	*Hard Brexit*	Time Frame	Features of model
Ciuriak, Xiao, Ciuriak, Dadkhan, Lysenko, Narayanan (2015)	GDP	*-1.03%*		*-2.76%*	2030	57 sectors 28 economies
Dhingra, Huang, Ottaviano, Pessoa, Sampson, Van Reenen (2017)	Welfare (measured by real consumption per capita)	*-1.34%**		*-2.66%**	10+ years after Brexit	31 sectors 35 regions
Ries, Hafner, Smith, Burwell, Egel, Han, Stepanek, Shatz (2017)	GDP	*3.2 p.p. better than hard Brexit*	*3.0 p.p better than hard Brexit*	*-4.90%*	2029	30 sectors
Ebell and Warren (2016)	GDP	*-1.5% to -2.1%*	*-1.9% to -2.3%*	*-2.7% to -3.7%*	2030	na
HM Treasury (2016)	GDP	*-3.8%*	*-6.2%*	*-7.5%*	15 years after leaving EU	
HMG (2018)	GDP	*-1.6%*	*-4.8%*	*-7.7%*	2030	12 sectors**
Kierzenkowski, Pain, Rusticelli, Zwart (2016)	GDP	*-2.7%****	*-5.1%***	*-7.7%***	2030	57 sectors 61 economies
Cambridge Econometrics (2018)	GVA	*-1.0%*		*-3.0%*	2030	70 sectors (EU), 44 sectors (ROW) 59 regions

* These estimates give the static effect.

** In the slides that were leaked and reported in the press there were 12 sectors; the underlying model is likely to have more sectors

*** The scenarios in Kierzenkowski et al. are labelled 'optimistic', 'central' and 'pessimistic' and do not necessarily correspond to 'Soft Brexit', 'FTA' or 'Hard Brexit'. However, to simply the table, Kierzenkowski et al. estimate for 'optimistic' is listed under 'Soft Brexit', 'central' is listed under 'FTA' and 'pessimistic' is listed under 'Hard Brexit'.

In advance of the EU referendum, Ciuriak et al. (2015) used a multi-sector, multi-region CGE model to compare the trade-related costs of the UK's exit with the potential benefits of alternative trade policies. Their simulation results suggest that by 2030 a 'hard' Brexit (to WTO terms) will lower UK's real GDP by 2.8% while remaining in the EEA will result to a fall of only 1%.

Dhingra et al. (2017) also use a CGE trade model with 31 sectors and 35 countries (regions) to estimate long-term costs of Brexit. They model the effects of 'soft' Brexit (the UK remains in the Single Market) and 'hard' Brexit (the UK and the EU trade on WTO terms) by simulating changes in trade costs. They find that increases in bilateral tariffs and non-tariff barriers between the UK and the EU, and the exclusion of the UK from future EU integration would lead to UK welfare losses ranging from 1.3% under the 'soft' Brexit scenario to 2.7% under the 'hard' Brexit scenario. Their analysis also suggests that other EU countries may lose out – especially those that trade intensively with the UK (e.g., Ireland) – but that some countries outside the EU may experience a small welfare gain because of a trade diversion effect.

Ries et al. (2017) derive the implications of eight Brexit scenarios for the UK, EU27 and the US using a CGE model. The results suggest the WTO-rules Brexit is most costly for the UK: within ten years, the UK's real GDP would be 4.9% lower than if the UK had remained within the EU. The EU27 Member States suffer also but less than the UK, with a fall in EU27 GDP of 0.7%. The US, on the other hand, may experience a modest gain of 0.02% of GDP, resulting from reduced trade diversion. Among all Brexit options, the three-way UK-EU27-US TTIP-style FTA is the least damaging for the UK, followed by the Norwegian model (second best), and a customs union for goods (third best).

Ebell and Warren (2016) assume Brexit will affect the UK economy through three main channels: (a) reductions in trade with EU countries following a modest increase in tariff barriers; (b) reduction in FDI (in particular, services FDI); and (c) reduction in UK's fiscal contribution to the EU. The authors model three Brexit scenarios: 'Norway', 'Switzerland' and 'WTO', all of which assume that the UK leaves the Customs Union, that rules of origin are applied to UK exports to the EU and that the UK loses access to EU's free trade arrangements with third parties. Using the NiGEM model to derive the macroeconomic effects of the trade changes, they find that by 2030, GDP is projected to be between 1.5% and 3.7% lower compared to a baseline scenario where the UK remains in the EU. They also find that real wages and consumption are set to fall: real wages by between 2.2% and 6.3%, and consumption by between 2.4% and 5.4%. These declines are expected to be more pronounced than the decline in GDP because of the permanent deterioration in the terms of trade, and shift towards savings. This projected fall in GDP equates to some 0.1% GDP reduction for each 1% reduction in trade.

HM Treasury (2016) analyses the impact of leaving the EU on trade and FDI, and what this means for GDP and productivity under three scenarios: EEA membership, a negotiated bilateral trade agreement (like Canada) and trade on WTO terms (like Russia or Brazil). It finds that in the long term – over 15 years – there will be a loss of GDP ranging from 3.4% to 4.3% under the 'EEA' scenario, from 4.6% to 7.8% under the 'negotiated bilateral agreement' alternative, and from 5.4% to 9.5% under the 'WTO' alternative. Potential economic losses may be greater if the UK loses out on the benefits of wider EU economic reforms such as the implementation of the 'Services Directive', the Digital Single Market, single energy market, and the completion of ongoing trade negotiations with the US, Japan, India and with the ASEAN and Mercosur countries. More recent work by the HM Government (2018), which was widely leaked in the press, was based on CGE model and suggested aggregate welfare losses of a similar order of magnitude, ranging from -1.6% to -7.7% depending on the scenario.

Comparing Brexit to a 'tax on GDP' that would impose a persistent and rising cost on the economy, Kierzenkowski et al. (2016), again on the basis of a CGE model, project that by 2020 GDP would be some 3% smaller than if the UK had remained part of the EU. Over the long term, there will also be additional structural impacts working through the channels such as capital, immigration, lower technical progress and labour productivity being held back by lower FDI and a smaller pool of skilled workers, all of which are expected to result in considerably greater costs. By 2030, UK GDP may be some 5% lower under the 'central' Brexit scenario. Around two-fifths of this derives from lower levels of productivity driven by lower trade openness. Even in the 'optimistic' Brexit scenario, GDP of the UK will fall 2.7% by 2030, while the 'pessimistic' scenario may lead to 7.7% fall.

Work commissioned by the Mayor of London from Cambridge Econometrics (2018) studies the effects of Brexit on the UK economy and produces a sub-regional forecast for key sectors in London. The forecasts distinguish between five different scenarios, ranging from status quo, a two year transition with membership of the Single Market or the Customs Union thereafter, to falling back to WTO terms. Compared to the status quo, maintaining membership of the Single Market but not the Customs Union could lead to a loss of £18.6bn in GVA and 176,000 jobs across the UK by 2030. A 'hard' Brexit without a transition period could result in a loss of £54.4bn in GVA and 482,000 jobs across the UK. The report suggests that while some 87,000 jobs could be lost in London alone, the capital could suffer much less from Brexit than the rest of the country, increasing geographic inequalities across the UK.

4. Model, Data and Calibration

4.1. The Model

Our analysis is based on a partial equilibrium model of the possible impact of Brexit on prices, exports, imports and output in 122 manufacturing industries, based on the 4-digit classes of ISIC Revision 4. The model has a multi-market structure, and in this application has four markets: the United Kingdom, the rest of the European Union (EU27), 67 countries with which the EU currently has Free Trade Agreements (FTA67) and a residual rest of the world (ROW).

There are two variants of the model. The core model (referred to as ICF below) is based on Krugman's (1979, 1980, 1981) model of trade under imperfect competition, and our partial equilibrium application builds on the work of Smith and Venables (1988). The model assumes each industry produces differentiated products under conditions of increasing returns to scale. Modelling of demand follows Dixit and Stiglitz (1977), with constant elasticity demand functions for individual products. This means consumers have a 'love of variety' in any one product: wine drinkers like wine from different Spanish producers, and also wine from different Australian producers; and demand for an individual variety depends on its price relative to an aggregate product price index. Demand for the aggregate product is a function of the aggregate price index. The imperfect substitutability of different firms' varieties gives rise to imperfect competition, in which firms have market power and set prices above marginal cost. Increasing returns mean that growth in a firm's sales in one market reduces its cost of production and leads to expansion in other markets too. Markets are segmented and firms act as Bertrand competitors, setting prices in each market to maximise profits taking competitors' prices as given. The number of firms in each country are constant. (A fuller description of the model is given in the appendix.)

A second version of the model which we use for sensitivity analysis (referred to as ARM) applies the standard Armington assumption on the demand side (Armington, 1969). This means that products are differentiated only by place of production (consumers treat all Spanish wine as homogenous but different from all Australian wine), so that the product varieties produced in different countries are imperfect substitutes for each other. In this variant of the model, we assume perfect competition so individual firms do not have market power, and supply behaviour is described by a standard upward sloping supply function.

Because we use partial equilibrium analysis, our results should not be seen as making 'predictions' about the precise sectoral effects of Brexit. The actual effects will depend in good part on the changes in policy which we model, but in addition on structural factors which are not captured by the model, on the second-order adjustments in factor markets and markets for intermediates, on other policy changes and shocks which cannot be predicted, as well as on longer run changes in investment. Our modelling aims to provide a consistent framework for evaluating orders of magnitude of the direct effects on manufacturing from different possible scenarios. This enables comparison across industries and sectors and across scenarios of the extent to which the different industries and sectors are vulnerable to the changes in trade costs implied by the UK leaving the EU.

4.2. Data

Our model requires data on production, bilateral trade flows and trade costs, where production and trade data are combined to capture domestic absorption (domestic consumption of domestic production). The model requires these data to be broken down by industry and by country (i.e., market). Data are collected for 2016.

There is a fundamental difference between the two sets of data: production data are collected on an activity basis while trade data are collected on a commodity basis. The two can be partially (and imperfectly) reconciled using concordance tables, but in sectors where the reconciliation was problematic, we used secondary sources of information on the share of production exported by each industry from the latest release of the World Input-Output Database (WIOD) (Timmer et al., 2015, Timmer et al., 2016) in order to adjust the underlying production data.

Trade, Production and Trade Costs: Data on gross output for the UK and the EU came from the OECD Structural and Demographic Business Statistics (SDBS) database for which the latest available data were for 2015. These were then adjusted on the basis of the growth in each countries' exports over the period 2015-16, assuming a constant ratio of exports to production.

We also need data for all other countries, aggregated to FTA67 and ROW. For these countries, production was estimated on the basis of the value of exports (for which more accurate data are available), together with information from WIOD on the ratio of exports to production in 2014.[5]

The source of bilateral goods trade data used is the UN Comtrade database at the 6-digit level of the Harmonised System (HS). These data were then aggregated to the ISIC 4-digit level using concordance tables. To reduce the number of missing observations at the HS 6-digit subheading level and improve the accuracy of trade flows data, we averaged imports data and mirror flows based on partners' exports data.[6]

To account for the costs of trade between countries, we also need information on tariffs and non-tariff measures (NTMs). Bilateral tariff data were taken from UNCTAD's TRAINS database, at the HS 6-digit level and then as with the trade data aggregated to the ISIC 4-digit level using concordance tables. We use the average effectively applied (AHS) tariff rates which take into account the tariffs applied between countries with preferential agreements be they bilateral in the case of free trade areas, or unilateral in the case of schemes such as the Generalised System of Preferences. In the absence of preferential treatment, the AHS rates are the Most Favoured Nation (MFN) rates. In our analysis, we use import-weighted average tariff rates. Where 2016 data were missing, we used tariff data for earlier years.[7] A similar approach was adopted by Caliendo and Parro (2015) in their study of the trade and welfare effects of NAFTA.

Unlike tariffs, NTMs are not simple numbers – "they are complex legal texts that are not easily amenable to quantification, comparison, or even standard formatting" (Cadot et al., 2012). Because of the growing recognition of the importance of non-tariff barriers on trade flows, there has been increasing interests among trade economists and policymakers in their measurement (Berden and Francois, 2015). As with specific duties, this essentially amounts to calculating the ad-valorem equivalent of an NTM, which is the rate of a hypothetical tariff that would generate an equivalent reduction in imports. These estimates can then be fed into the partial equilibrium model to simulate the effect of trade policy changes involving NTMs. The econometric quantification of NTM equivalents for different countries and industries is complex, and there is considerable variation in estimates reported across different studies.

In this paper, we make use of the NTM equivalents estimated by Cadot and Gourdon (2016), who compute these for sanitary and phytosanitary regulations and other technical barriers to trade for 21 sections of the HS classification using a direct price-gap estimation approach.[8] We use these estimates partly because they are based on the most recent data; partly because, as Cadot and Gourdon (2016) note, their estimates lie within a single-digit range and are somewhat lower than previous estimates based on older data (which may reflect the progressive phasing out of instruments such as quantitative restrictions in many countries); and partly because as they are computed for all 21 sections of the HS classification, and can be linked with a fair degree of precision to our 122 manufacturing industries. A further advantage of the NTM estimates of Cadot and Gourdon (2016) is that they distinguish between the size of the NTM barriers between countries that are part of a regional trade agreement (RTA) and those that are not. This enables us to use their NTM equivalents in the presence of deep integration clauses in RTAs as a proxy for the NTM-related trade costs within the Single Market. For any other bilateral trade relationships, we use the ad-valorem equivalents of NTMs in the absence of an RTA.

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[5] The WIOD data are at a higher level of aggregation and cover 56 manufacturing sectors, which we then corresponded with our 122 sectors.

[6] In theory, the reported imports of country A from country B should match country B's reported exports to country A, but in practice discrepancies exist. This is for several reasons. Firstly, imports are recorded as cif (cost insurance freight) and exports are recorded as fob (free on board), and this difference in recording may amount to some 10-20% difference in trade values. Secondly customs authorities typically have a greater obligation to accurately record import flows (for revenue purposes), in comparison to export flows. Thirdly, the export documentation may record the first destination of the flow, which in the case of transhipments may not be the same as the final destination.

[7] Based on the HS2012 classification.

[8] The price-gap estimation approach involves estimating the ad-valorem equivalent of an NTM by comparing directly the price of products in the NTM's presence with that of similar products on markets without; it does not assume that NTMs reduce trade as quantity-based approaches would do. The price-gap approach relies on the availability of and comparability of price data.

Model Parameters: Elasticities: The model also requires estimates of the elasticity of substitution between different varieties of the same product, the elasticity of demand for each product in aggregate and the elasticity of supply. Empirical evidence on such elasticities is somewhat limited. Hertel et al. (2007) described the history of estimating the substitution elasticities governing trade flows in the CGE models as being "checkered at best".

Broda and Weinstein (2006) estimate elasticities of substitution among goods at various levels of aggregation and different time periods. Their results show that as product categories become more disaggregated, goods become increasingly substitutable. For an earlier period (1972-1988), the simple average substitution elasticity is 17 for 7-digit TSUSA goods, but only 7 for 3-digit goods. They also show that the mean (and median) elasticity has fallen over time (to 12 for 10-digit HTS goods and 4 for 3-digit goods for 1990-2001), suggesting that goods have become more differentiated. Broda and Weinstein (2006) also demonstrate that more homogenous (less differentiated) goods are more substitutable. In our work, we categorise our 122 4-digit ISIC Rev.4 classes as either homogenous or differentiated. For homogenous goods industries, we set the value of substitution elasticity at 6. For differentiated-goods industries, we set the value of substitution elasticity at 3. These values tie in with a simple average substitution elasticity of 4 for 3-digit HTS goods for 1990-2001 in Broda and Weinstein (2006).

A recent attempt at estimating import demand elasticities is the work of Ghodsi et al. (2016b), who compute importer-specific import demand elasticities for 167 countries and 5,124 commodities at the 6-digit level of the HS1996, for the period 1996-2014. Across all HS 6-digit products and countries, they find a mean value of import demand elasticity of -1.20, with significant variation across countries and across products. In our analysis, we use import demand elasticities of Ghodsi et al. (2016), aggregated to the level of our 122 industries.

In the baseline version of the imperfect competition version of the model, we assume increasing returns to scale with an arbitrarily chosen elasticity of 0.1. For the Armington version of our model, we also need to specify supply elasticities. Although some partial equilibrium models adopt the simplification that supply elasticities are infinite (Hallren and Riker, 2017) this will depend on the characteristics of the industry in question. We assume a high but finite supply elasticity, with a value set at 6 for domestic suppliers to domestic market (i.e., UK supplier to UK market, EU27 suppliers to EU27 market, etc.) and at 15 for other suppliers. (All the elasticities used in this paper are reported in the Appendix Table 15.)

5. Scenarios and Results

We model the impact of Brexit on 122 manufacturing industries under five different possible Brexit scenarios. These range from EEA membership, which most resembles the status quo and is our 'softest' Brexit scenario; to the 'hard' No Trade Deals scenario, where the UK reverts to trading on WTO terms with all countries. Table 2 provides a summary of the key features of each.

Table 2: Comparison of five Brexit scenarios

	Features			
Scenario	SM	FTA with EU	FTA with FTA67	FTA with ROW
1: EEA	✓	✓	✓	×
2: FTA with EU and FTA67	×	✓	✓	×
3: No Trade Deals	×	×	×	×
4: FTA with FTA67 and ROW	×	×	✓	✓
5: Unilateral Free Trade	×	×	×	×

Scenario 1: EEA This is our 'softest' Brexit scenario, where we assume that the UK leaves the EU CU, but signs an FTA with the EU, has full membership of the Single Market, and grandfathers the 67 existing EU FTAs. Leaving the CU would entail increased border inspections to check whether goods imported into the EU from the UK are UK goods covered by the FTA or non-UK goods which may be subject to EU tariffs. Based on Centre for Economic Policy Research (2013), Francois et al. (2013), Carrère and de Melo (2015), Anson et al. (2005), Cadot et al. (2005) and Hayakawa (2011), we have assumed

border inspections would increase trade costs between the UK and the EU by 3.5% (this is at the lower end of the estimates in the literature). All other trade costs between the UK and other countries, including the EU, are unchanged. This increase in trade costs between the UK and EU is then included in all subsequent experiments.

Scenario 2: FTA with EU and FTA67 The UK is again assumed to leave the CU, and in addition leaves the Single Market. However, it signs an FTA with the EU, and bilateral tariffs with the EU remain at zero. Leaving the Single Market increases the non-tariff related cost of EU-UK trade, however, because of the need for conformity assessments. We model this by assuming that non-tariff barriers increase. We use the lower FTA-inclusive NTM estimates of Cadot and Gourdon (2016).[9] As before, we assume that the costs of trade between the UK and non-EU countries do not change.

Scenario 3: No Trade Deals In this scenario, we assume that there is no trade agreement between the UK and the EU and no rolling over of the EU's FTAs to the UK, so the UK trades on WTO terms with all countries. The UK, EU, and EU FTA countries (FTA67) apply MFN tariffs on bilateral trade with the UK. The UK is assumed to adopt the current EU28 tariff schedules. Because the WTO has made less progress than the EU in reducing non-tariff barriers (Dhingra et al., 2016) and in liberalising trade in services (Borchert, 2016; Dhingra and Sampson, 2016), there would also be an increase in non-tariff barriers between the UK and the EU which we assume can be represented by the higher non-FTA Cadot and Gourdon (2016) estimates.

Scenario 4: FTA with FTA67 and ROW The preceding three scenarios model successive reductions in the UK's access to EU and EU-FTA countries. Here, we assess the extent to which the impact of reductions in access to the EU market could be offset by the UK signing free trade agreements with third countries. We therefore assume no UK-EU trade deal, but also that the UK signs FTAs with all non-EU countries. This involves rolling over the existing EU FTAs and agreeing new FTAs with *all* other countries with which the EU does not currently have agreements. This is a very generous modelling of the potential of the UK to make new trade deals. As the data show that existing EU FTAs do not reduce duties on all tariff lines to zero, we model this scenario as a reduction in UK tariffs on imports from the rest of the world (ROW) to the level currently applied on imports from the EU-FTA countries, and a reduction in the ROW tariff on imports from the UK to the level applied by the FTA countries. These new global trade deals are also assumed to imply a reduction in NTMs.

Scenario 5: Unilateral Free Trade This is effectively a version of the No Trade Deals scenario in that the UK leaves the EU with no trade deal, fails to roll over existing EU FTAs and fails to agree new trade deals. The UK, however, chooses to unilaterally remove tariffs on all imports, while other countries do not reciprocate. UK tariffs on imports fall to zero, but UK exports are subject to MFN tariffs. In this scenario, in the spirit of unilateral free trade, we also assume the UK will treat imports from most countries as acceptable from a regulatory perspective, which we model by assuming NTMs on imports into the UK from all countries are set at the lower level that apply to trade flows between countries that have FTAs and that therefore recognise each other's regulatory regimes. We also assume all trade flows to and from the UK face border costs of 3.5%. Even if there are no tariffs to be collected on imports, border controls will be needed to ensure regulatory and legal requirements are met. With the UK out of the EU, border controls will be required to collect VAT on imports too, and there would be border inspections of imports from the EU as well as from the rest of the world.

Table 3 details the assumptions made about the changes in trade costs across the different scenarios. The top panel gives the situation in the base. Each of the subsequent panels only has an entry if there is any change from the base. So if you take the EEA panel, the only change from the base is in border costs. In the second experiment, once again we have the change in border costs but in addition there is an increase in NTMs.

[9] In practice, membership of the Single Market lowers the costs associated with NTMs, but does not eliminate them. In our modelling of Brexit, however, we adopt a simplifying assumption that the Single Market keeps costs of NTMs at zero, while an EU-UK FTA is assumed to have low NTMs and trade in the absence of an FTA, conducted on WTO rules, has high NTMs. The estimates of low and high NTMs are based on what Cadot and Gourdon (2016) define as NTM level with and without an RTA, respectively. See Cadot and Gourdon (2016) for further details.

Table 3: Trade costs assumptions in five Brexit scenarios

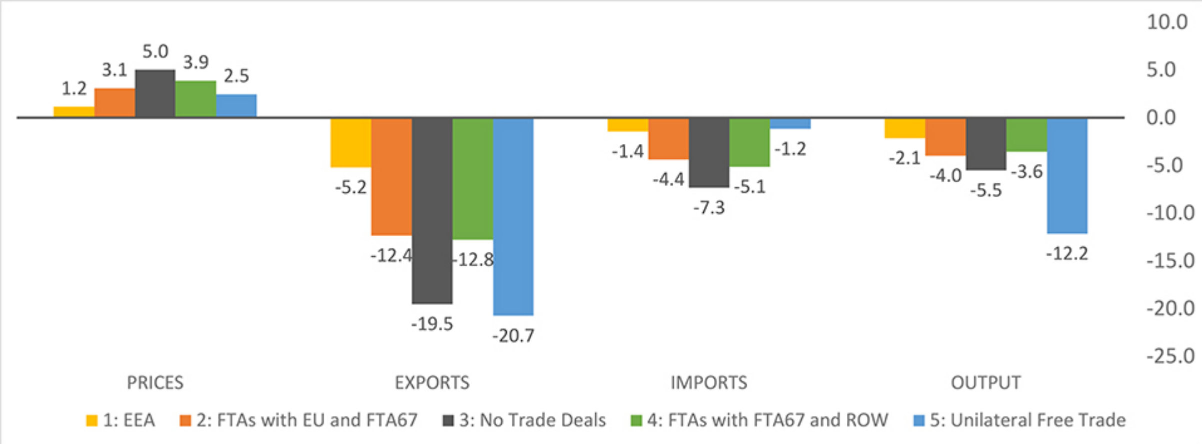
Reporter: UK		Partner		
Scenario	**Trade Costs**	**EU**	**FTA67**	**ROW**
Base	Tariffs	0%	PREF	AHS
	NTMs	0%	Low	High
	Border costs	0%	3.5%	3.5%
	Deviations from Base			
1: EEA	Tariffs			
	NTMs			
	Border costs	3.5%		
2: FTA with EU and FTA67	Tariffs			
	NTMs	Low		
	Border costs	3.5%		
3: No Trade Deals	Tariffs	MFN	MFN	
	NTMs	High	High	
	Border costs	3.5%		
4: FTA with FTA67 and ROW	Tariffs	MFN		PREF
	NTMs	High		Low
	Border costs	3.5%		
5: Unilateral Free Trade	Tariffs		0%	0%
	NTMs	Low		Low
	Border costs	3.5%		

Notes: AHS: effectively applied tariff rate, which allows for preferential agreements. MFN: Most Favoured Nation tariff rate. Low and High NTMs refer to estimates of average NTMs with and without RTAs, respectively; these estimates for 21 HS Sections are sourced from Cadot and Gourdon (2016). In Brexit scenarios 1-4, the deviations from base trade costs are bi-directional (i.e., apply to the UK and the relevant partner country). In the Unilateral Free Trade scenario, however, what we report as deviations from base apply to the UK imports. The UK exports in the Unilateral Free Trade scenario are subject to the MFN tariffs, high NTMs and 3.5% border costs in all three markets (EU, FTA67, ROW).

5.1. Average Impact

Before looking at how Brexit might affect individual manufacturing industries, we first set out the 'average' impact of Brexit across all industries for each of the scenarios, showing the effects on prices, exports, imports and output. Figure 1 shows that as we step through Scenarios 1, 2 and 3, from 'softer' to 'harder' versions of Brexit, the negative impacts on UK manufacturing increase in more or less equal steps. For instance, the aggregate decline in output goes from -2.1%, to -4.0% to -5.5%. The improbable achievement of FTAs with every single country outside the EU (Scenario 4) would only partially mitigate the effects of having no FTA with the EU, leading to an output decline of -3.6%. Unilateral Free Trade (Scenario 5) has the biggest impact on UK output, leading to a 12.2% decline. This is driven by the substantial decline in the UK exports, which are subject to the MFN tariffs of other countries; and substitution away from domestically produced goods towards imports, which with the removal of tariffs become relatively cheaper.

Figure 1: How different manufacturing scenarios will impact on prices, exports, imports and output in the manufacturing sector



These aggregate impacts are the sum of the effects on each of the 122 individual industries. How each industry adjusts to the changes in tariffs and NTMs arising from the different scenarios depends on several factors: first, results will be driven by the size of the experiment (changes in trade costs) in each industry; second, impacts will depend on the underlying structure of UK trade (industries where a high proportion of output is exported, and where a high proportion of exports are destined for the EU will see a bigger impact on exports as a result of any change in bilateral trade costs); and third, the underlying parameters of the model and notably the elasticities of both supply and demand will impact on the results.

To understand these drivers, we have run a stylised set of regressions on the outcome variables of interest – output, prices, exports and imports – in scenarios 1-3 of the imperfect competition version of the model.[10] The regressions are normalised such that the beta coefficients are the regression coefficients obtained by first standardising all variables as z-scores to have a mean of 0 and a standard deviation of 1. Hence, the coefficients refer to how many standard deviations a dependent variable will change in response to one standard deviation change in the explanatory variable.

Table 4: Impact of Brexit on manufacturing sectors: regression results

Scenarios	1-2-3	1-2-3	1-2-3	1-2-3
Model	ICF	ICF	ICF	ICF
Dependent variable	prices	exports	imports	output
Main variables				
Simulated UK:EU tariff costs	0.100***	-0.217***	-0.336***	0.118***
Simulated UK:EU non-tariff costs	0.242***	-0.515***	-0.575***	0.227***
UK share of UK market	-0.014	0.009	-0.412***	-0.369***
EU share of UK market	0.577***	0.052*	-0.105***	0.289***
UK share of UK sales	-0.047	-0.190***	-0.046	0.732***
EU share of UK sales	0.031	-0.421***	-0.040	-0.508***
Parameters				
Elasticity: demand	0.015	-0.036*	-0.052**	-0.002
Elasticity: substitution	-0.028	-0.536***	-0.209***	-0.111***
Number of firms	-0.001	0.016	-0.024	-0.011
Fixed effects				
Scenario fixed effects	Yes	Yes	Yes	Yes
Industry fixed effects	No	No	No	No
R^2	0.787	0.882	0.820	0.617
Adjusted R^2	0.781	0.879	0.815	0.605
N	366	366	366	366

Notes: Table reports results from normalised regressions, which use z-scores as LHS and RHS variables. The dependent variable is the z-score of the simulated percentage change in prices / output / exports / imports for individual 122 manufacturing industries. Standard errors are presented in parentheses, asterisks indicate *** = 1%

[10] We include only these three scenarios as they focus on Brexit scenarios where trade with the EU and other countries becomes more restrictive.

significance level; ** = 5% significance level and * = 10% significance level. ICF: imperfect competition partial equilibrium model with decreasing marginal costs.

In the first panel of Table 4, we consider the size of the experiment and find that increases in tariff and non-tariff costs impact on prices, trade and output. On average, the impact of changes in non-tariff costs is greater than the impact of changes in tariffs and this is true across all the outcome measures, simply because the changes in non-tariff barriers are larger.

The middle panel of the table identifies core structural features of the data which impact on the results and where we identify the role of:

- UK share of UK market: the share of total demand in the UK for a given good which is met by UK production.
- EU share of UK market: the share of total demand in the UK for a given good which is met by imports from the EU27.
- UK share of UK sales: the share of total UK production of a given good which is sold domestically.
- EU share of UK sales: the share of total UK production of a given good which is exported to the EU27.

Consider first the impact on prices. Predictably, the higher the EU share in the UK market the bigger the price rise.

Turning to exports, the most important structural feature is the EU share of UK sales: rising trade costs have a more negative effect on exports where the EU share in UK sales is higher. Similarly, the higher the EU share of the UK market the bigger the negative impact of increasing trade costs on imports. We also see that the higher is the UK share of the UK market the bigger is the decline in imports: if the UK share of the UK market is high, it is easier to switch to UK suppliers.

Changes in imports and exports then drive the changes in output through three main channels: (a) domestic protection may enable domestic producers to expand output; (b) domestic protection raises prices so lowers demand so may reduce output; and (c) raising the tariff or NTM costs of exporting to the EU reduces UK exports and hence sales. On average, we see that the higher the share of total UK production which is sold in the UK the bigger the increase in UK production: effect (a) dominates (b) and (c). There is a similar effect from the EU share of the UK market. Protection makes EU suppliers less attractive and the more they sell to the UK initially the bigger this effect will be.

In the bottom panel, we consider the role of key demand parameters. The elasticities of demand are only significant for exports and imports, where as expected the higher is the elasticity of demand the larger is the negative impact on trade flows. The elasticity of substitution plays a more important role for all outcome variables. The higher the elasticity, the easier it is for consumers to switch between products from different sources, and the larger therefore are the impacts on trade, prices and output.

5.2. Impact on Different Industries

The average results mask significant variation in how Brexit may affect different manufacturing industries. Here, we discuss the distribution of the changes in prices, exports, imports and output for three of our Brexit scenarios: the softest EEA (Scenario 1), No Trade Deals (Scenario 3) and Unilateral Free Trade (Scenario 5). This discussion highlights the wide variation in the results and also the differences across the three experiments.

Distribution of Changes: There is considerable variation across industries in the impact of Scenario 3 (No Trade Deals) on UK prices, with increases ranging from close to zero to 15%. The median industry experiences an increase in prices equal to 4.3%, and for five industries, prices rise by more than 10%. The distribution of price changes is broadly similar for Scenario 1 (EEA), but the magnitude of these changes is smaller.

Although the Unilateral Free Trade scenario reduces all tariffs on imports (which serves to reduce prices), it also involves an increase in border costs between the UK and the EU, and an increase in NTMs. Additionally, as firms produce under conditions of increasing returns to scale, the reduction in output by UK firms from reduced protection causes some increase in costs and hence prices. The net effect is therefore that for most industries prices rise, with a price reduction for some ten industries. This decline in prices is in most cases small (between 0% and 3%), except for sugar where it is 14%. This is because sugar has an extremely high ad-valorem tariff of 74%.

Turning to trade flows, all three scenarios lead to export declines for all industries, with the effects being strongest for Scenario 5 (Unilateral Free Trade) and weakest for Scenario 1 (EEA). For most industries, imports are also expected to fall after Brexit, with some industries (such as dairy products) experiencing a decline in import value of almost 90% in Scenario 3 (No Trade Deals). There are 17 industries that see imports grow under the No Trade Deals scenario, but these rises in imports are projected to be relatively modest (less than 2%). This requires some explanation. In the No Trade Deals scenario trade costs between the UK, the EU, and the EU-FTA countries rise, which would suggest a decline in imports. However, it also implies a decline in exports. Where exports are a significant share of production, the decline in exports leads to a decline in output and a corresponding increase in prices as firms move up their average costs curves. This reduces the competitiveness of UK firms domestically and can lead to a net rise in imports.

Finally, we turn to changes in output for individual industries. Unlike prices (which are largely projected to increase) and trade (largely projected to fall), there is a more mixed picture for output changes. This is because, as discussed earlier, there are three channels through which changes in imports and exports impact on output. In Scenario 1 (EEA) and Scenario 3 (No Trade Deals) output is projected to fall for some two-thirds of the industries but to increase for the rest. The Unilateral Free Trade scenario is more likely than other Brexit scenarios to lead to output declines, with the worst affected industry (sugar) projected to see a close to 90% drop in output (and an output decline of 11% for the median industry). By comparison, the industry which has the largest negative impact under the EEA and No Trade Deals scenarios (fibre optic cables) is projected to see output decline by 19% and 52%, respectively.

Most and Least Affected Industries: We have seen a relatively wide distribution of impacts across the 122 manufacturing industries. Tables 5-7 show the ten industries with the largest increases and decreases in output across three of our scenarios: EEA, No Trade Deals and the Unilateral Free Trade. For these industries, we report the percentage change in output, trade (exports and imports) and the percentage change in prices. As a comparison, we also report the respective changes for the median industry.

As discussed earlier, the impacts on the most and the least vulnerable manufacturing industries are driven primarily by the structure of existing trade flows and level of trade barriers. In the EEA scenario, given our assumption that all industries are affected uniformly by the higher border inspection cost of 3.5%, it is the underlying structure of trade which matters most. For example, in the industry with the largest increase in output (sawmilling and planing of wood), 93% of UK output is sold domestically, only 5% of UK output is exported to the EU, and UK producers account for 34% of total domestic sales. Conversely, in the industry that sees the biggest decline at nearly 20% (fibre optic cables), less than 4% of UK output is sold domestically, 46% of UK output is exported to the EU, and the EU supplies 55% of UK sales.

In both the No Trade Deals and the Unilateral Free Trade scenarios there are differential changes in trade costs (tariffs and NTMs) across industries. For example in the Unilateral Free Trade experiment the industry which declines the most is sugar, which does not appear in the list of top 10 most affected industries for either of the other experiments. The explanation is that the high level of protection afforded to sugar, which has an average ad-valorem equivalent (AVE) import-weighted EU MFN tariff of 74%, and non-tariff AVE of 17%, is being reduced in this scenario.

Table 5: EEA: top ten – bottom ten industries

ISIC4 Code	Industry	% change in output (quantity)	% change in exports (value)	% change in imports (value)	% change in prices
10 industries with largest increase in output					
1610	Sawmilling and planing of wood	8.58	-8.26	-4.80	1.00
2392	Clay building materials	6.94	-6.90	-6.84	0.91
1621	Veneer sheets and wood-based panels	4.84	-11.02	-4.49	1.11
2396	Cutting, shaping and finishing of stone	4.57	-6.71	-4.74	0.51
1393	Carpets and rugs	4.46	-7.85	-4.85	1.51
1074	Macaroni, noodles, couscous, etc.	4.14	-11.93	-3.08	2.09
1030	Processing/preserving of fruit,vegetables	3.78	-10.72	-8.51	0.72
1050	Dairy products	2.73	-10.14	-12.47	0.72
1701	Pulp, paper and paperboard	2.63	-8.45	-4.88	1.59
1010	Processing/preserving of meat	2.29	-11.24	-10.24	0.58
Median		-1.97	-5.10	-1.32	1.13
10 industries with largest decrease in output					
1410	Wearing apparel, except fur apparel	-9.54	-6.69	-0.01	1.04
1391	Knitted and crocheted fabrics	-10.11	-14.76	0.09	1.05
1511	Tanning/dressing of leather; dressing of fur	-10.31	-12.00	-1.72	2.21
2011	Basic chemicals	-10.59	-12.67	-1.61	1.90
1430	Knitted and crocheted apparel	-10.60	-7.38	-0.05	1.00
1520	Footwear	-10.80	-7.66	0.02	1.61
2013	Plastics and synthetic rubber in primary forms	-13.00	-16.22	-1.51	2.57
1312	Weaving of textiles	-13.71	-15.90	-0.11	1.60
3212	Imitation jewellery and related articles	-15.08	-16.49	0.47	1.49
2731	Fibre optic cables	-18.92	-16.13	0.22	1.94

Table 6: No Trade Deals: top ten – bottom ten industries

ISIC4 Code	Industry	% change in output (quantity)	% change in exports (value)	% change in imports (value)	% change in prices
10 industries with largest increase in output					
1074	Macaroni, noodles, couscous, etc.	91.18	-60.40	-37.10	14.10
2392	Clay building materials	29.81	-25.71	-28.50	3.39
1030	Processing/preserving of fruit,vegetables	24.79	-56.08	-51.45	3.80
1393	Carpets and rugs	24.54	-30.37	-22.94	5.98
1610	Sawmilling and planing of wood	23.85	-22.40	-13.21	2.57
1050	Dairy products	22.65	-65.02	-88.98	4.24
1621	Veneer sheets and wood-based panels	22.03	-40.41	-18.82	4.12
1010	Processing/preserving of meat	18.34	-72.00	-71.56	3.48
1062	Starches and starch products	13.70	-46.80	-79.17	2.65
2396	Cutting, shaping and finishing of stone	13.14	-19.57	-13.52	1.40
Median		-5.59	-19.16	-6.13	4.28
10 industries with largest decrease in output					
2013	Plastics and synthetic rubber in primary forms	-29.80	-46.40	-9.29	10.46
1420	Articles of fur	-29.83	-21.22	1.41	9.23
1512	Luggage,handbags,etc.;saddlery/harness	-29.91	-22.81	0.47	6.37
2420	Basic precious and other non-ferrous metals	-31.82	-27.97	0.09	3.19
1312	Weaving of textiles	-37.71	-49.38	-3.17	7.04
3212	Imitation jewellery and related articles	-39.05	-44.97	1.35	4.86
1410	Wearing apparel, except fur apparel	-40.87	-31.30	-0.07	6.27
1430	Knitted and crocheted apparel	-45.39	-34.71	-0.38	6.81
1520	Footwear	-45.39	-35.21	0.10	8.53
2731	Fibre optic cables	-52.17	-46.94	0.75	7.13

Table 7: Unilateral Free Trade: top ten – bottom ten industries

ISIC4 Code	Industry	% change in output (quantity)	% change in exports (value)	% change in imports (value)	% change in prices
10 industries with largest increase in output					
1610	Sawmilling and planing of wood	18.90	-24.00	-10.75	2.17
1050	Dairy products	7.61	-67.27	-49.45	2.97
2392	Clay building materials	7.41	-32.53	-9.94	1.56
2396	Cutting, shaping and finishing of stone	6.08	-22.13	-7.21	0.85
1622	Builders' carpentry and joinery	3.12	-30.65	-20.24	0.32
1030	Processing/preserving of fruit,vegetables	2.52	-60.35	-15.63	1.74
1062	Starches and starch products	2.38	-49.58	-28.47	1.23
3020	Railway locomotives and rolling stock	2.23	-12.34	-3.99	2.63
2394	Cement, lime and plaster	2.22	-31.44	-30.13	1.60
2395	Articles of concrete, cement and plaster	1.40	-33.23	-22.09	0.26
Median		-11.10	-20.14	-0.77	2.01
10 industries with largest decrease in output					
2011	Basic chemicals	-41.46	-45.52	3.16	3.80
1410	Wearing apparel, except fur apparel	-42.50	-31.74	0.30	-2.57
2013	Plastics and synthetic rubber in primary forms	-46.42	-53.25	0.62	5.57
1430	Knitted and crocheted apparel	-46.75	-35.11	0.35	-2.67
1520	Footwear	-47.33	-35.74	0.24	-3.07
3212	Imitation jewellery and related articles	-48.68	-49.53	3.07	1.50
1391	Knitted and crocheted fabrics	-50.95	-57.95	11.01	-0.03
1312	Weaving of textiles	-53.45	-56.27	8.30	1.75
2731	Fibre optic cables	-53.71	-47.82	1.18	3.48
1072	Sugar	-88.53	-88.27	74.21	-14.33

Several of the industries with largest output increases are in food processing. These industries tend to have high levels of protection (both tariffs and NTMs) and a higher share of imports from EU than non-EU countries (and often a significant share of demand met by domestic producers). Erecting relatively high barriers on imports from the EU (as in No Trade Deals scenario) may stimulate some additional domestic production to serve domestic markets, while unilaterally removing all tariffs on imports (as in Unilateral Free Trade scenario) will not add much extra competition as non-EU imports are relatively small.

By contrast, many industries in textiles and clothing have the largest projected decreases in output. In 'wearing apparel' less than 2% of UK demand is met by domestic producers and close to 70% of demand by non-EU producers. Because tariffs are relatively high, domestic producers are vulnerable to increased competition from non-EU producers following removal of tariffs under the Unilateral Free Trade scenario. In addition, a sizeable proportion of exports is destined for the EU (71%) and a much smaller share (7%) is sold in the UK, so domestic producers are vulnerable under the EEA and the No Trade Deals scenarios.

Considering the extremes of the distribution offers only part of the story. Table 8 gives the Spearman rank correlation coefficients across the three experiments reported above for prices, trade and output. These coefficients indicate whether the vulnerability of different manufacturing industries in one Brexit scenario makes them similarly vulnerable to another Brexit scenario. The correlations are strongest between the EEA and the No Trade Deals scenarios, and reflect the similarity in vulnerability across the scenarios.

Table 8: Spearman's rank correlation coefficient

	Prices	Exports	Imports	Output
EEA & No Trade Deals	0.886	0.903	0.961	0.954
EEA & Unilateral Free Trade	0.769	0.896	0.672	0.846
No Trade Deals & Unilateral Free Trade	0.643	0.992	0.585	0.759

5.3. Impact on Different Sectors

We now aggregate our 122 industries into sectors to give a broader picture of how UK manufacturing may be affected. The cells in the tables in this section of the paper contain colour-coded data bars, where blue bars capture negative changes and yellow bars capture positive changes.

Impact on Broader Sectoral Groupings: Here, we aggregate the results for individual industries into 11 broad sectors.[11] Table 9 shows that across the scenarios the biggest increase in prices is for Transport, and for Chemicals and Pharmaceuticals. The one sector where prices decrease is Textiles, Apparel and Footwear – and only where the UK chooses to unilaterally remove all tariffs (Scenario 5). The smallest impact on prices is for Wood, Paper and Printing.

Table 9: Sectoral groups and Brexit: impact on prices

Percentage change in prices

	Scenario 1: EEA	Scenario 2: FTAs with EU and FTA67	Scenario 3: No Trade Deals	Scenario 4: FTAs with FTA67 and ROW	Scenario 5: Unilateral Free Trade
Food processing	0.6	2.3	3.7	2.9	1.5
Textiles, apparel and footwear	1.2	2.5	6.1	1.3	-0.9
Wood, paper and printing	0.4	0.8	1.0	0.8	0.7
Chemicals and pharmaceuticals	2.0	4.9	7.5	6.1	4.4
Rubber and plastic	0.9	2.1	3.7	2.7	1.5
Metals and non-metallic minerals	0.7	1.4	2.7	1.2	0.8
Electronic and scientific	1.4	3.3	4.3	3.3	2.6
Electrical	1.4	3.1	4.7	3.3	2.2
Machinery	1.7	4.0	5.6	4.5	3.2
Transport	1.8	5.5	9.8	8.4	4.8
Other	1.1	2.6	3.3	2.6	2.0

Table 10 suggests Food Processing is most at risk of a significant fall in exports after Brexit. This decline is 38% under Scenario 3 (No Trade Deals) and 41% under Scenario 5 (Unilateral Free Trade). As with exports, Table 11 shows that Food Processing may see the biggest declines in imports, ranging from 3% in the Unilateral Free Trade scenario to 46% in the No Trade Deals scenario. Overall, these larger declines in exports and imports for Food Processing are driven in good part by the size of tariff and NTMs in this sector, coupled with the extent of trade with the EU.

Table 10: Sectoral groups and Brexit: impact on exports

Percentage change in exports

	Scenario 1: EEA	Scenario 2: FTAs with EU and FTA67	Scenario 3: No Trade Deals	Scenario 4: FTAs with FTA67 and ROW	Scenario 5: Unilateral Free Trade
Food processing	-6.9	-24.7	-38.4	-33.7	-40.8
Textiles, apparel and footwear	-8.4	-16.5	-33.5	-29.7	-35.5
Wood, paper and printing	-9.2	-14.8	-20.2	-13.0	-21.5
Chemicals and pharmaceuticals	-6.6	-14.4	-21.3	-14.6	-23.0
Rubber and plastic	-4.4	-9.9	-17.4	-13.4	-18.2
Metals and non-metallic minerals	-6.7	-12.6	-25.5	-7.1	-26.8
Electronic and scientific	-4.0	-9.2	-11.9	-9.1	-12.2
Electrical	-5.3	-11.6	-16.7	-11.0	-18.2
Machinery	-3.3	-7.3	-10.7	-6.0	-11.0
Transport	-3.0	-8.7	-14.2	-9.1	-15.2
Other	-3.7	-8.3	-11.1	-8.2	-11.5

Table 11: Sectoral groups and Brexit: impact on imports

Percentage change in imports

	Scenario 1: EEA	Scenario 2: FTAs with EU and FTA67	Scenario 3: No Trade Deals	Scenario 4: FTAs with FTA67 and ROW	Scenario 5: Unilateral Free Trade
Food processing	-6.8	-26.9	-46.3	-28.6	-3.0
Textiles, apparel and footwear	-0.2	-0.5	-1.3	-0.2	0.8
Wood, paper and printing	-5.9	-11.1	-13.7	-12.1	-8.9
Chemicals and pharmaceuticals	-0.8	-2.0	-3.9	-3.3	-0.1
Rubber and plastic	-2.2	-5.1	-9.4	-6.5	-2.0
Metals and non-metallic minerals	-1.0	-2.2	-3.3	-2.6	-1.0
Electronic and scientific	-0.2	-0.5	-0.6	-0.5	-0.2
Electrical	-1.0	-2.4	-3.9	-2.3	-0.2
Machinery	-0.4	-0.9	-1.3	-1.2	-0.4
Transport	-0.7	-2.3	-4.5	-4.1	-1.5
Other	-0.8	-1.7	-2.1	-1.6	-0.9

[11] These are somewhat broader than the 2-digit divisions of ISIC Rev.4. The appendix provides full details.

Finally, Table 12 shows that for most sectors output falls under all scenarios, most notably for Textiles, Apparel and Footwear. In contrast, Food Processing, and Wood, Paper and Printing experience output growth, though not in all scenarios. Under Unilateral Free Trade, Food Processing output declines by 8%. The impact of trade liberalisation on some sectoral groups should not be taken as an argument for protection (which comes at the expense of consumers and intermediate goods purchasers who face higher prices), and it is important to recognise that should the UK unilaterally remove all tariffs, domestic producers in some industries may suffer very heavily when exposed to import competition from foreign producers.

Table 12: Sectoral groups and Brexit: impact on output

Percentage change in output

	Scenario 1: EEA	Scenario 2: FTAs with EU and FTA67	Scenario 3: No Trade Deals	Scenario 4: FTAs with FTA67 and ROW	Scenario 5: Unilateral Free Trade
Food processing	0.9	4.4	9.2	3.1	-8.3
Textiles, apparel and footwear	-8.0	-15.2	-28.4	-28.4	-37.0
Wood, paper and printing	1.1	2.5	2.9	3.1	0.8
Chemicals and pharmaceuticals	-6.6	-13.6	-18.8	-12.7	-24.3
Rubber and plastic	-0.9	-1.9	-2.8	-2.7	-7.3
Metals and non-metallic minerals	-2.8	-4.8	-10.6	-1.1	-14.3
Electronic and scientific	-3.8	-8.5	-10.9	-8.4	-12.3
Electrical	-2.8	-5.6	-7.0	-5.2	-13.8
Machinery	-3.4	-7.3	-10.4	-5.4	-12.0
Transport	-2.4	-6.2	-8.8	-4.5	-13.4
Other	-1.5	-3.2	-4.4	-3.2	-6.2

It is also worth noting that if instead of aggregating results for 122 industries into 11 broad sectors, we aggregate data first and run simulations for 11 sectors, we get some differences in the final results.[12] Aggregation makes a difference to the analysis: the aggregated results conducted at a disaggregated level can be significantly different from the results of the same analysis done at the aggregated level. And with most policy being made and applied at a very detailed level, this emphasises the importance of detailed analyses at disaggregated levels to better understand the effects of policy changes.

R&D Intensity: R&D-intensive sectors are often considered to be important drivers of economic growth, and the UK Government's industrial strategy places an emphasis on building a knowledge and innovation-led economy through R&D investment (Clark, 2017). Understanding how Brexit may affect high R&D sectors relative to low R&D sectors may shed light on possible longer-term implications of Brexit, as changes to R&D-intensive sectors in trade and output will have consequential effects on investment and training. Using an OECD taxonomy,[13] we aggregate the 122 manufacturing industries into four groups depending on the R&D intensity of their main production activities (high, medium-high, medium and medium-low R&D intensity).[14]

The impacts on output, shown in Table 13, depend on the net effects of the import and export changes. The medium-low R&D group sees the biggest declines in imports as protection of domestic industries rises. It also experiences a decline in exports, but because the share of sales going to the UK is high the net impact on output is small and in two of the scenarios positive. Conversely, the more R&D-intensive group shows output declining in all scenarios, with the biggest drop in output expected for the medium-high R&D group, followed by the high R&D group. This reflects the high proportion of their sales, which goes to the EU.

The fact that high and medium-high R&D industries are more at risk of a significant decline in domestic production than medium and medium-low R&D industries has implications for the UK Government's ambition to support economic growth and drive productivity through R&D and innovation.

[12] The latter results are not reported here, but available from the authors on request.
[13] The OECD taxonomy links 3-digit groups of ISIC Rev.4 to different R&D-intensity groups, and is available at: http://www.oecd-ilibrary.org/science-and-technology/oecd-taxonomy-of-economic-activities-based-on-r-d-intensity_5jlv73sqqp8r-en.
[14] Full detail on this aggregation is in the appendix. The OECD taxonomy also defines low R&D sectors, but none of the manufacturing industries is classed as low R&D intensity in the OECD taxonomy.

Table 13: R&D intensity and Brexit: impact on prices, trade and output

Percentage change in prices

	Scenario 1: EEA	Scenario 2: FTAs with EU and FTA67	Scenario 3: No Trade Deals	Scenario 4: FTAs with FTA67 and ROW	Scenario 5: Unilateral Free Trade
High R&D	1.5	3.8	5.0	4.0	3.2
Medium-high R&D	2.0	5.3	9.2	7.7	4.7
Medium R&D	0.8	1.7	3.1	1.6	1.1
Medium-low R&D	0.6	1.8	2.9	2.0	1.1

Percentage change in exports

	Scenario 1: EEA	Scenario 2: FTAs with EU and FTA67	Scenario 3: No Trade Deals	Scenario 4: FTAs with FTA67 and ROW	Scenario 5: Unilateral Free Trade
High R&D	-3.3	-8.1	-10.5	-7.2	-10.8
Medium-high R&D	-5.0	-11.8	-18.6	-12.3	-20.1
Medium R&D	-6.0	-11.9	-23.1	-8.1	-24.3
Medium-low R&D	-7.6	-20.2	-31.7	-25.7	-33.7

Percentage change in imports

	Scenario 1: EEA	Scenario 2: FTAs with EU and FTA67	Scenario 3: No Trade Deals	Scenario 4: FTAs with FTA67 and ROW	Scenario 5: Unilateral Free Trade
High R&D	-0.2	-0.6	-0.7	-0.7	-0.2
Medium-high R&D	-0.8	-2.4	-4.5	-3.8	-0.9
Medium R&D	-0.9	-2.1	-3.4	-2.6	-0.9
Medium-low R&D	-3.7	-11.8	-19.5	-12.5	-2.5

Percentage change in output

	Scenario 1: EEA	Scenario 2: FTAs with EU and FTA67	Scenario 3: No Trade Deals	Scenario 4: FTAs with FTA67 and ROW	Scenario 5: Unilateral Free Trade
High R&D	-3.5	-8.3	-10.6	-7.2	-11.8
Medium-high R&D	-4.3	-9.2	-13.1	-8.0	-19.0
Medium R&D	-2.8	-5.0	-10.2	-2.2	-14.0
Medium-low R&D	-0.2	0.8	2.2	-0.2	-7.6

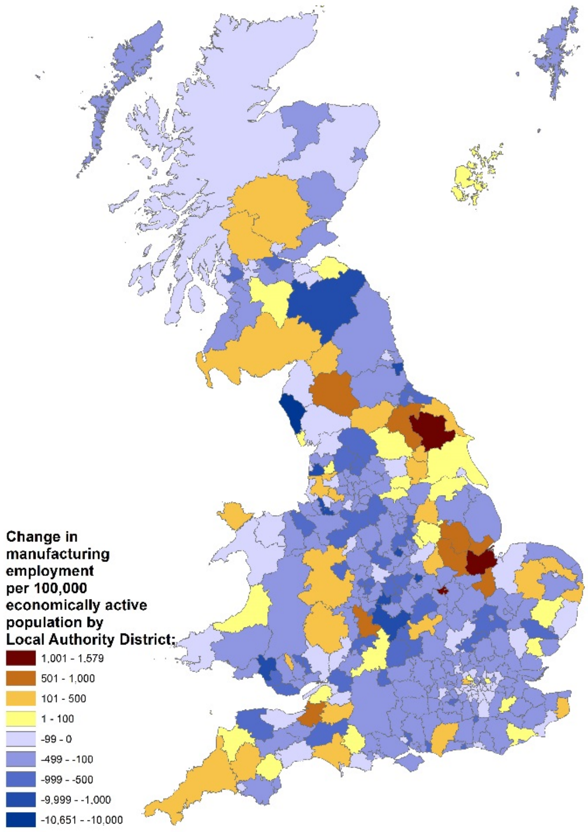
6. Impact on Places and Workers

The projected changes in output, trade and prices, will have implications on consumers, producers and workers across the country. Previous studies which have analysed the impact of Brexit on consumer prices and households include Clarke et al. (2017) for the UK and Lawless and Morgenroth (2018) for the Republic of Ireland. In this section, we focus on the labour market implications of Brexit, and examine how changes in output after Brexit may impact on employment in different parts of the country, and different types of workers.

6.1. Locational Impact of Brexit

To assess locational impact, we assume that employment effects are proportional to output changes (i.e., a 5% reduction in output results in a 5% reduction in employment), and combine this with data on the regional distribution of employment in different manufacturing industries. This enables us to translate our projections of the output effects of different scenarios into employment effects for different parts of the country. The results for the No Trade Deals scenario are shown in Figure 2 where we map the possible impacts in proportion to the size of the economically active population in each area. The areas are defined by local authority districts.

Figure 2: Impact of No Trade Deals Brexit on manufacturing employment across Local Authority Districts



Source: Authors' own analysis; Business Register and Employment Survey, 2016; Annual Population Survey, 2016; Ordnance Survey Boundary-Line.

Most areas are expected to experience a manufacturing employment loss. Copeland is predicted to be the most negatively impacted with more than 10,000 jobs lost for every 100,000 economically active residents (see: Table 14). This arises partly because Copeland's small pool of workers is concentrated in manufacturing (nuclear fuel processing), and partly because in our data nuclear processing is aggregated with a number of other non-ferrous metal activities, some of which experience big Brexit-related shocks. Other areas at risk of a substantial decline in manufacturing employment include Fylde (where employment is concentrated in the manufacturing of aircraft), Stratford-on-Avon (manufacturing of motor vehicles) and Leicester (manufacturing of wearing apparel). This reflects these areas' higher reliance on jobs in sectors that see bigger impacts from Brexit.

One in six areas may see employment growth. Among these, South Holland, Corby and Ryedale have the biggest projected positive effects from Brexit on employment in manufacturing. Our modelling suggests that the No Trade Deals version could add more than 1,000 manufacturing jobs for every 100,000 economically active residents in these areas. This reflects their higher reliance on jobs in sectors, notably food processing, that see bigger positive impacts from protection given by higher trade costs with the EU.

In Table 14 we also compare the employment vulnerability of different areas under the No Trade Deals and the EEA scenarios, identifying the ten districts with the largest increase in employment and the ten districts with the largest decrease, as well as the median outcome.

Table 14: Impact of No Trade Deals and EEA Brexit scenarios on manufacturing employment: top ten and bottom ten local authority districts

Scenario: No Trade Deals	change in employment	Scenario: EEA	change in employment
10 local authority districts with largest increase in employment (per 100,000 economically active population)			
South Holland	1,579	South Holland	208
Corby	1,249	Fenland	127
Ryedale	1,105	Eden	72
Fenland	842	North Kesteven	69
North Kesteven	812	Boston	67
Wychavon	807	South Kesteven	65
Boston	712	Hambleton	44
Hambleton	632	Wychavon	42
Sedgemoor	608	Dumfries and Galloway	39
South Kesteven	587	Ryedale	36
Median	-199	**Median**	-80
10 local authority districts with largest decrease in employment (per 100,000 economically active population)			
Scottish Borders	-1,085	Sunderland	-378
Solihull	-1,142	Knowsley	-395
Halton	-1,156	Halton	-425
Sunderland	-1,288	Flintshire	-427
Knowsley	-1,337	Leicester	-438
City of London	-1,457	Neath Port Talbot	-446
Leicester	-1,548	Stratford-on-Avon	-471
Stratford-on-Avon	-1,761	City of London	-484
Fylde	-2,227	Fylde	-655
Copeland	-10,651	Copeland	-2,421

As noted earlier, in the EEA scenario it is the structure of trade and production that drives the differential sectoral outcomes, because all industries are affected uniformly by higher border inspection costs of 3.5% and there are no differential tariff or NTM changes. That underlying structure is significant for all the experiments, as reflected in the Spearman rank correlation coefficients reported in Table 8. Hence, industries most vulnerable under the EEA scenario are also most vulnerable under the No Trade Deals scenario. This explains why there is considerable overlap in the local authority districts which see the largest and smallest employment changes. Eight of the local authorities which see the biggest increase in employment under a No Trade Deal, are also those with the biggest employment increase under the EEA scenario. Similarly with regard to the largest decreases in employment, there are eight local authority districts which overlap. We see that Copeland ranks first for employment decreases under both scenarios; as does South Holland for employment increases.

Of course, it is the magnitude of those expected employment changes that is different between the scenarios. The 'hardest' No Trade Deals Brexit may cause a 10,000 employment loss per 100,000 economically active residents in Copeland – but under the 'softest' EEA Brexit the employment loss may be more like 2,400. The areas that might gain most employment under No Trade Deals may see more modest gains under the EEA scenario: for example, South Holland may gain close to 1,600 jobs for every 100,000 economically active residents under the 'hard' Brexit but only some 200 jobs under the 'soft' Brexit. The median local authority district loses 199 jobs per 100,000 economically active residents under No Trade Deals – and loses 80 jobs under the EEA scenario. We reiterate that our local employment effects concern solely manufacturing employment, and do not reflect the full potential effect of Brexit on employment. The full effects are likely to be bigger arising from any changes in access in services.[15]

[15] Analysing the pattern of UK regional services exports, Borchert and Tamberi (2018) find that regions such as the North East or the Midlands may potentially be more vulnerable to Brexit shocks because of the sectoral composition of their services exporters and their orientation towards EU markets. Chen et al. (2018), who constructed index for the regional GDP exposure to Brexit, find that it is many of the UK's economically weaker regions which are especially exposed to Brexit, with GDP exposure to Brexit being highest in the Midlands and the North of England.

6.2. Employment effects of Brexit

The variation in the possible impact on different manufacturing industries has wider labour market implications. In this section, we distinguish between high, medium, and low-skilled workers, and consider how the No Trade Deals and EEA scenarios might affect demand for different categories of workers. This is a static exercise, where the skills profile of different industries is taken as given and where we make no allowance for effects on labour supply decisions of workers, on training by firms, or on migration into the UK.

We use the information on number of workers by skill type and by industry class in main job from the Labour Force Survey quarterly data for April-June 2016.[16] We take the highest qualification of adults of working-age (HIQUL15D) as a proxy for skills, and in separating employed working-age adults into those with high, medium and low skills we adopted the following categorisation:[17]

- High skills: those with higher and further education
- Medium skills: those with A-levels, GCSE A*-C
- Low skills: those with no qualifications

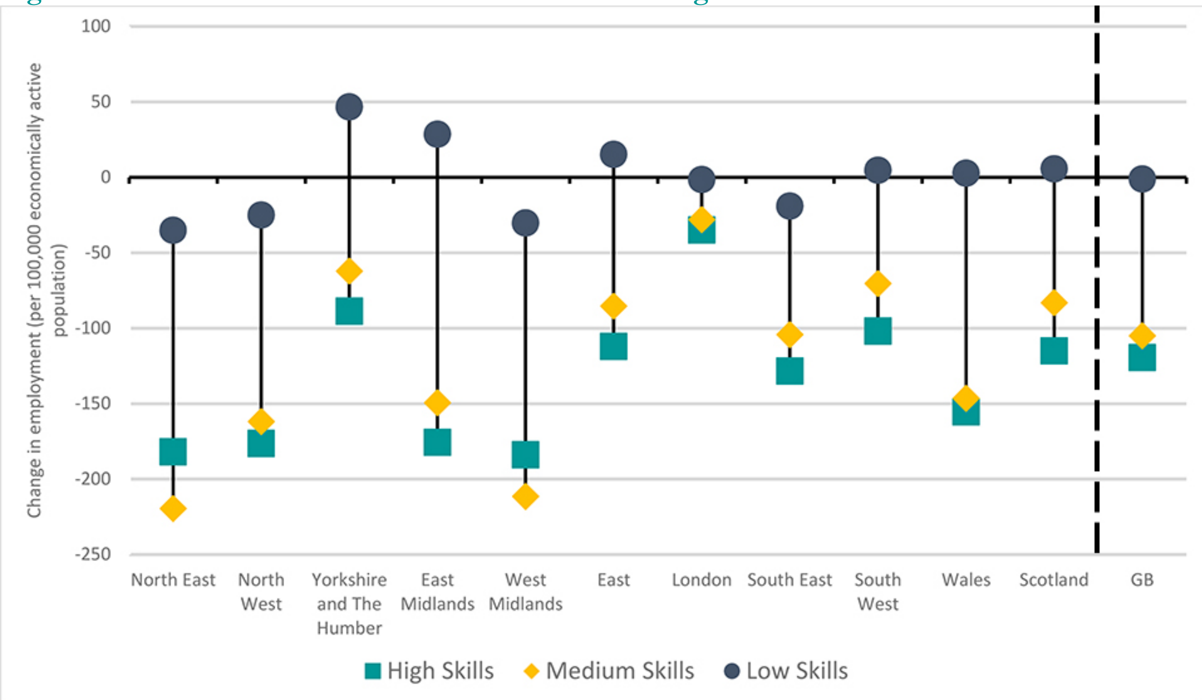
Using the output 'predictions' from No Trade Deals and EEA scenarios, we calculate how demand for these different categories of workers will change. We assume an industry shock applied uniformly across three categories of workers. For instance, if No Trade Deals Brexit leads to a 10% decline in output in the motor vehicle sector, we assume there will be a corresponding 10% reduction in demand for high-skilled / medium-skilled / low-skilled workers employed in the motor vehicle sector. Any differences in the impact of Brexit on demand for different categories of workers will therefore stem from (a) differential impact on different sectors (for example, Brexit will lead to a larger output fall in basic chemicals sector than in pharmaceuticals), and (b) differences in the skills profile of workers in these sectors (the workforce in basic chemicals sector is on average less highly skilled than in pharmaceuticals, with 36% of workers being classed as high skilled compared to 69% in pharmaceuticals).

Figure 3 shows the change in demand for high, medium and low-skilled workers across 11 regions of Britain for the No Trade Deals Brexit scenario; the changes in labour demand at the national level are also reported. Across most regions, the reduction in labour demand is more pronounced for high-skilled workers than for medium and low-skilled workers. The North East and the West Midlands are the only exceptions, where it is demand for medium-skilled workers that sees the largest reduction. While a No Trade Deals Brexit is expected to reduce demand for high and medium-skilled workers across all parts of the country, demand for low-skilled labour increases in six out of the 11 regions, with this growth being strongest in Yorkshire and the Humber. Growth in demand for low-skilled labour is highest in Yorkshire and the Humber because this region contains a higher proportion of sectors that may grow after Brexit, and those sectors tend to be intensive in low-skilled labour (most notably, food processing).

[16] We accessed the LFS data using nesstar, an online analysis tool of the UK Data Service, where relevant weights have been applied.

[17] Those respondents who answered 'Don't Know' (7) (HIQUL15D), did not answer the question (-8) or those to whom the question was 'Not Applicable' (-9) were excluded from the cross-tabulations.

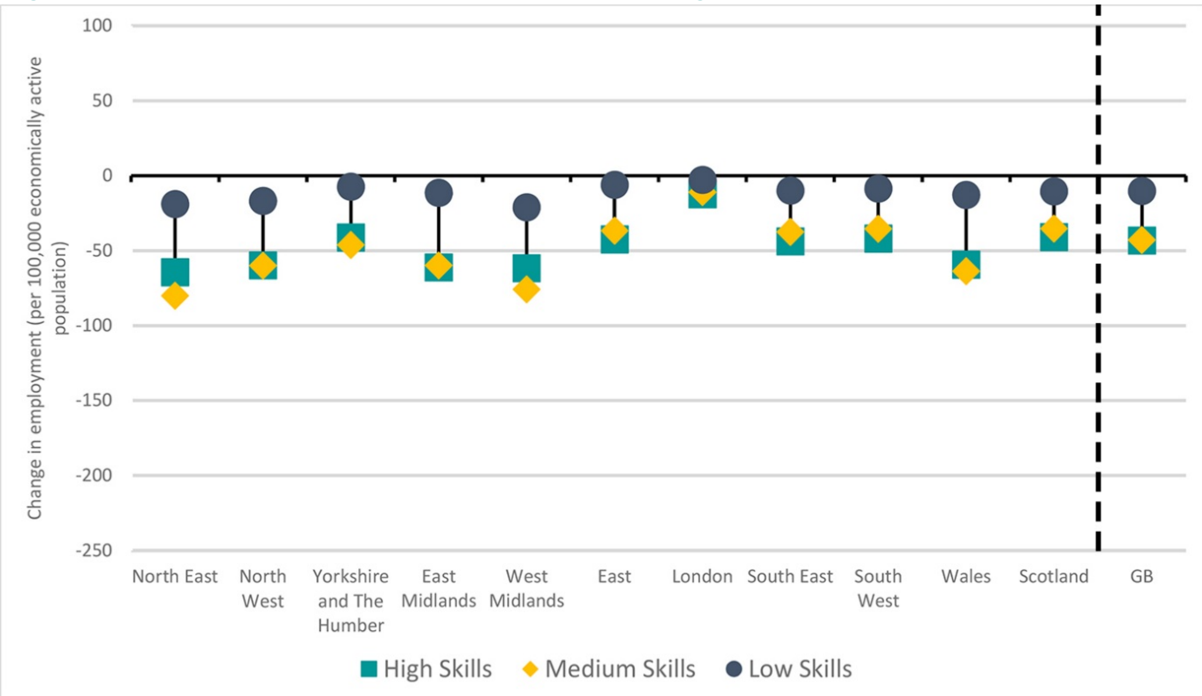
Figure 3: Demand for skills after Brexit across British regions: No Trade Deals Brexit scenario



Source: Authors' own analysis using Business Register and Employment Survey 2016; Annual Population Survey, 2016; Labour Force Survey April-June 2016.

We repeated the exercise for the EEA Brexit scenario, with results shown in Figure 4. In contrast to the No Trade Deals scenario, which may benefit low-skilled workers in some regions, all worker types in all parts of the country face reduced demand under the EEA scenario. As in the No Trade Deals, high and medium-skilled workers are more negatively affected than the low-skilled, but the reduction in demand for the former categories of workers is less pronounced under the EEA Brexit. The largest reduction in demand is for medium-skilled workers in the North East and the West Midlands. In London, changes in demand for high, medium and low-skilled workers are least pronounced, because compared to other regions a smaller proportion of the London's economy is in manufacturing.

Figure 4: Demand for skills after Brexit across British regions: EEA Brexit scenario



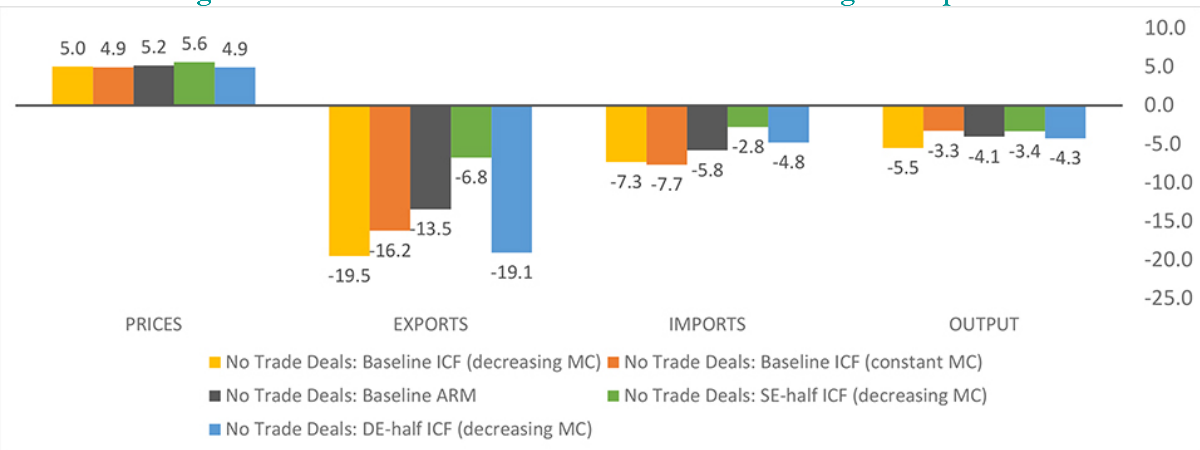
Source: Authors' own analysis using Business Register and Employment Survey 2016; Annual Population Survey, 2016; Labour Force Survey April-June 2016.

It is important to underline that the estimated change in demand for the three categories of workers (which we normalise by the size of the economically active population) is derived entirely from the simulated impact of Brexit on manufacturing, which is only 10% of the national economy.

7. Sensitivity Analysis

To check how robust the results were to modelling assumptions, we ran a set of simulations where we halved the elasticity of substitution and elasticity of demand. We also examined how the simulation results differed between different versions of the partial equilibrium model: the imperfect competition (ICF) model with decreasing marginal costs (i.e., the workhorse model), the imperfect competition model with constant marginal costs, and the 'standard' Armington (ARM) model. For these modelling alternatives, we set out the 'average' impact of No Trade Deals across all 122 manufacturing industries.

Figure 5: How sensitive are the results to the modelling assumptions?



Notes: ICF: imperfect competition partial equilibrium model. ARM: Armington model. MC: marginal costs. SE-half: simulations with substitution elasticity halved. DE-half: simulations with demand elasticity halved.

Figure 5 shows the impact on prices is robust to the underlying modelling assumptions, with the average impact ranging from 4.9 to 5.6% increase in the No Trade Deals scenario. The impact on trade varies somewhat more depending on the assumed parameter values: because the substitution elasticity capturing the ease with which consumers are able to switch between products from different sources, the effect on exports and to a lesser degree on imports is somewhat sensitive to the substitution elasticity, because it captures the ease with which consumers can switch between products from different sources. Changing the demand elasticity, on the other hand, changes the effect on imports but makes little difference to exports. The simulation results for output appear generally robust to the parameter values.

8. Conclusions

In this paper, we have outlined some of the possible implications of the UK's exit from the EU on 122 different manufacturing industries, as well as for broader sectoral aggregations. Using a partial equilibrium multi-market simulation model with an imperfectly competitive market structure, we have looked at how Brexit may impact on prices, exports, imports, and output in each of the manufacturing industries, and for different sector types.

None of the five Brexit scenarios that we model leads to a positive outcome for UK manufacturing on average: even EEA membership results in higher costs of trade between the UK and the EU, and in reduced market access compared with full membership of the EU. These higher costs will harm UK manufacturing.

Of the five Brexit scenarios we considered, Unilateral Free Trade has the biggest negative impact on UK manufacturing output because of the substantial decline in UK exports, which are subject to MFN tariffs in other countries; and because of substitution away from domestically produced goods towards imports, which become relatively cheaper with the removal of UK tariffs.

The results show that there is a considerable variation in how different manufacturing industries will be affected by Brexit. This differential impact of Brexit on manufacturing industries is driven primarily by the size of the changes in trade costs in different industries and the extent to which the industry depends on the EU market.

The variation in how different manufacturing industries will be affected by Brexit also generates considerable differences in the impact of Brexit on different geographical areas and different categories of workers. These differences, coupled with the fact that most trade policy is made and applied at a very detailed level, highlight the importance of detailed disaggregated analysis for understanding the effects of Brexit on different industries and different UK regions.

An important conclusion is that high tech and medium-high tech sectors are more at risk from Brexit than are medium and medium-low tech sectors. Brexit may lead to expansion in some sectors (especially in food processing), but the effects are small and come at the expense of higher consumer and intermediate goods prices.

That high and medium-high tech sectors are more vulnerable to Brexit explains why across most regions the reduction in demand may be more pronounced for high-skilled workers than for medium and low-skilled workers. Specifically, Brexit seems likely to reduce demand for high and medium-skilled workers in all parts of the country, while in some regions demand for low-skilled workers may increase under the No Trade Deals scenario.

Lastly, we have looked at whether signing new trade deals can compensate for the loss of market access and trade with the EU. Our modelling of a scenario in which the UK leaves the EU without a deal but signs FTAs with all other countries in the world suggests that even these universal FTAs would not fully mitigate the loss of trade with the EU.

References

Anson, J., O. Cadot, A. Estevadeordal, J. de Melo, A. Suwa-Eisenmann, and B. Tumurchudur (2005). Rules of Origin in North-South Preferential Trading Arrangements with an Application to NAFTA. *Review of International Economics 13*(3), 501– 517.

Armington, P. S. (1969). A Theory of Demand for Products Distinguished by Place of Production. *Staff Papers (International Monetary Fund) 16*(1), 159–178.

Berden, K. and J. Francois (2015). Quantifying Non-Tariff Measures for TTIP. Paper No. 12 in the CEPS-CTR project "TTIP in the Balance" and CEPS Special Report No. 116/July 2015.

Borchert, I. (2016). Services Trade in the UK: What is at Stake? UKTPO Briefing Paper 6, UK Trade Policy Observatory, University of Sussex.

Borchert, I. and N. Tamberi (2018). Brexit and Regional Services Exports: A Heat Map Approach. UKTPO Briefing Paper 14, UK Trade Policy Observatory, University of Sussex.

Broda, C. and D. E. Weinstein (2006). Globalization and the Gains from Variety. *The Quarterly Journal of Economics 121*(2), 541–585.

Cadot, O., A. Estevadeordal, and A. Suwa Eisenmann (2005). Rules of Origin as Export Subsidies. CEPR Discussion Papers 4999, Centre for Economic Policy Research.

Cadot, O. and J. Gourdon (2016). Non-Tariff Measures, Preferential Trade Agreements, and Prices: New Evidence. *Review of World Economics (Weltwirtschaftliches Archiv) 152*(2), 227–249.

Cadot, O., M. Malouche, and S. Sáez (2012). *Streamlining Non-Tariff Measures: A Toolkit for Policy Makers.* Washington, DC: The World Bank.

Caliendo, L. and F. Parro (2015). Estimates of the Trade and Welfare Effects of NAFTA. *The Review of Economic Studies 82*(1), 1–44.

Cambridge Econometrics (2018). Preparing for Brexit. Technical report, Cambridge Econometrics.

Carrère, C. and J. de Melo (2015). Are Different Rules of Origin Equally Costly? Estimates from NAFTA. In J. de Melo (Ed.), *Developing Countries in the World Economy*, Chapter Chapter 11, pp. 277–298. World Scientific.

Centre for Economic Policy Research (2013). Estimating the Economic Impact on the UK of a Transatlantic Trade and Investment Partnership (TTIP) Agreement between the European Union and the United States. Final Project Report, Centre for Economic Policy Research.

Chen, W., B. Los, P. McCann, R. Ortega-Argilés, M. Thissen, and F. Oort (2018). The Continental Divide? Economic Exposure to Brexit in Regions and Countries on Both Sides of The Channel. *Papers in Regional Science 97*(1), 25–54.

Ciuriak, D., J. Xiao, N. Ciuriak, A. Dadkhan, D. Lysenko, and G. Narayanan (2015). The Trade-Related Impact of a UK Exit from the EU Single Market. Open Europe Research Report, Ciuriak Consulting Incorporated.

Clark, G. (2017). Record Boost to R&D and New Transport Fund to Help Build Economy Fit for the Future. Retrieved from: http://www.gov.uk/government/news/record-boost-to-rd-and-new-transport-fund-to-help-build-economy-fit-for-the-future/.

Clarke, S., I. Serwicka, and L. A. Winters (2017). Changing Lanes: The Impact of Different Post-Brexit Trading Policies on the Cost of Living. Technical Report, Resolution Foundation and the UK Trade Policy Observatory.

Dhingra, S., H. Huang, G. Ottaviano, J. a. P. Pessoa, T. Sampson, and J. Van Reenen (2017). The Costs and Benefits of Leaving the EU: Trade Effects. CEP Discussion Paper No 1478, Centre for Economic Performance, London School of Economics and Political Science, London, UK.

Dhingra, S., G. Ottaviano, T. Sampson, and J. Van Reenen (2016). The Consequences of Brexit for UK Trade and Living Standards. CEP BREXIT Analysis No.2, Centre for Economic Performance, London School of Economics and Political Science, London, UK.

Dhingra, S. and T. Sampson (2016). Life After Brexit: What Are the UK's Options Outside the European Union? CEP BREXIT Analysis No.1, Centre for Economic Performance, London School of Economics and Political Science, London, UK.

Dixit, A. K. and J. E. Stiglitz (1977). Monopolistic Competition and Optimum Product Diversity. *American Economic Review 67*(3), 297–308.

Ebell, M. and J. Warren (2016). The Long-Term Economic Impact of Leaving the EU. *National Institute Economic Review 236*(1), 121–138.

Francois, J., M. Manchin, H. Norberg, O. Pindyuk, and P. Tomberger (2013). Reducing Transatlantic Barriers to Trade and Investment: An Economic Assessment. IIDE Discussion Papers 20130401, Institute for International and Development Economics.

Ghodsi, M., J. Grübler, and R. Stehrer (2016b). Import Demand Elasticities Revisited. wiiw Working Paper No. 132, The Vienna Institute for International Economic Studies.

Hallren, R. and D. Riker (2017). An Introduction to Partial Equilibrium Modeling of Trade Policy. Economics Working Paper Series No. 2017-07-B, U.S. International Trade Commission.

Hayakawa, K. (2011). Measuring Fixed Costs for Firms' Use of A Free Trade Agreement: Threshold Regression Approach. *Economics Letters 113*(3), 301–303.

Hertel, T., D. Hummels, M. Ivanic, and R. Keeney (2007). How Confident Can We Be of CGE-Based Assessments of Free Trade Agreements? *Economic Modelling 24*(4), 611–635.

HM Treasury (2016). *HM Treasury Analysis: The Long-term Economic Impact of EU Membership and the Alternatives*. HM Treasury, London.

Kierzenkowski, R., N. Pain, E. Rusticelli, and S. Zwart (2016). The Economic Consequences of Brexit. OECD Economic Policy Papers No. 16, OECD, Paris.

Krugman, P. R. (1979). Increasing Returns, Monopolistic Competition, and International Trade. *Journal of International Economics 9*(4), 469–479.

Krugman, P. R. (1980). Scale Economies, Product Differentiation, and the Pattern of Trade. *American Economic Review 70*(5), 950–959.

Krugman, P. R. (1981). Intraindustry Specialization and the Gains from Trade. *Journal of Political Economy 89*(5), 959–973.

Lawless, M. and E. Morgenroth (2018). Brexit and Irish Consumers. ESRI Special Article, Economic and Social Research Institute, Dublin.

Lydgate, E. and L. A. Winters (2018). Deep and Not Comprehensive? What the WTO Rules Permit for a UK-EU FTA. *World Trade Review*, 129.

Ries, C. P., M. Hafner, T. D. Smith, F. G. Burwell, D. Egel, E. Han, M. Stepanek, and H. J. Shatz (2017). After Brexit: Alternate Forms of Brexit and Their Implications for the United Kingdom, the European Union and the United States. Technical report, RAND Corporation, Santa Monica, CA.

Smith, A. and A. J. Venables (1988). Completing the Internal Market in the European Community: Some Industry Simulations. *European Economic Review 32*(7), 1501–1525. Special Issue on 'Market Competition, Conflict and Collusion'.

Tetlow, G. and Stojanovic, A. (2018). Understanding the Economic Impact of Brexit. Institute for Government, London.

Timmer, M., B. Los, R. Stehrer, and G. de Vries (2016). An Anatomy of the Global Trade Slowdown based on the WIOD 2016 Release. GGDC Research Memorandum GD-162, Groningen Growth and Development Centre, University of Groningen, Groningen.

Timmer, M. P., E. Dietzenbacher, B. Los, R. Stehrer, and G. J. Vries (2015). An Illustrated User Guide to the World Input-Output Database: the Case of Global Automotive Production. *Review of International Economics 23*(3), 575–605.

A Appendix figures and tables

Table 15: Categorisation of 122 manufacturing industries

Manufacturing industry (4-digit class of ISIC Rev.4)	Sectoral group	R&D group	Elasticity of substitution	Elasticity of demand
1. 1010 Processing/preserving of meat	FOOD	ML	6	1.001
2. 1020 Processing/preserving of fish, etc.	FOOD	ML	6	0.960
3. 1030 Processing/preserving of fruit, vegetables	FOOD	ML	6	0.965
4. 1040 Vegetable and animal oils and fats	FOOD	ML	6	1.065
5. 1050 Dairy products	FOOD	ML	6	0.950
6. 1061 Grain mill products	FOOD	ML	6	1.062
7. 1062 Starches and starch products	FOOD	ML	6	1.034
8. 1071 Bakery products	FOOD	ML	3	0.931
9. 1072 Sugar	FOOD	ML	6	0.999
10. 1073 Cocoa, chocolate and sugar confectionery	FOOD	ML	3	0.809
11. 1074 Macaroni, noodles, couscous, etc.	FOOD	ML	6	1.007
12. 1079 Other food products n.e.c.	FOOD	ML	6	0.936
13. 1080 Prepared animal feeds	FOOD	ML	6	1.056
14. 1101 Distilling, rectifying and blending of spirits	FOOD	ML	3	0.987
15. 1102 Wines	FOOD	ML	3	1.082
16. 1103 Malt liquors and malt	FOOD	ML	3	1.076
17. 1104 Soft drinks, mineral waters, other bottled waters	FOOD	ML	3	0.947
18. 1200 Tobacco products	NC	ML	3	0.911
19. 1311 Preparation and spinning of textile fibres	TEX	ML	6	1.044
20. 1312 Weaving of textiles	TEX	ML	6	0.957
21. 1391 Knitted and crocheted fabrics	TEX	ML	6	0.943
22. 1392 Made-up textile articles, except apparel	TEX	ML	3	0.832
23. 1393 Carpets and rugs	TEX	ML	6	1.011
24. 1394 Cordage, rope, twine and netting	TEX	ML	6	0.863
25. 1399 Other textiles n.e.c.	TEX	ML	6	0.939
26. 1410 Wearing apparel, except fur apparel	TEX	ML	3	1.006
27. 1420 Articles of fur	TEX	ML	3	0.832
28. 1430 Knitted and crocheted apparel	TEX	ML	3	1.057
29. 1511 Tanning/dressing of leather; dressing of fur	TEX	ML	6	0.930
30. 1512 Luggage, handbags, etc.; saddlery/harness	TEX	ML	3	0.906
31. 1520 Footwear	TEX	ML	3	0.979
32. 1610 Sawmilling and planing of wood	WOOD	ML	6	1.008
33. 1621 Veneer sheets and wood-based panels	WOOD	ML	6	1.037
34. 1622 Builders' carpentry and joinery	WOOD	ML	6	0.900
35. 1623 Wooden containers	WOOD	ML	6	1.188
36. 1629 Other wood products; articles of cork, straw	WOOD	ML	6	0.938
37. 1701 Pulp, paper and paperboard	WOOD	ML	6	1.082
38. 1702 Corrugated paper and paperboard	WOOD	ML	6	0.997

Table 15 – *Continued from previous page*

Manufacturing industry (4-digit class of ISIC Rev.4)	Sectoral group	R&D group	Elasticity of substitution	Elasticity of demand
39. 1709 Other articles of paper and paperboard	WOOD	ML	6	0.964
40. 1811 Printing	WOOD	ML	6	0.514
41. 1812 Service activities related to printing	WOOD	ML	6	0.973
42. 1820 Reproduction of recorded media	WOOD	ML	3	0.690
43. 1910 Coke oven products	NC	ML	6	1.005
44. 1920 Refined petroleum products	NC	ML	6	1.071
45. 2011 Basic chemicals	CHE	MH	6	1.013
46. 2012 Fertilizers and nitrogen compounds	CHE	MH	6	1.004
47. 2013 Plastics and synthetic rubber in primary forms	CHE	MH	6	1.059
48. 2021 Pesticides and other agrochemical products	CHE	MH	3	0.847
49. 2022 Paints, varnishes; printing ink and mastics	CHE	MH	3	0.921
50. 2023 Soap, cleaning and cosmetic preparations	CHE	MH	3	0.954
51. 2029 Other chemical products n.e.c.	CHE	MH	3	0.927
52. 2030 Man-made fibres	CHE	MH	3	1.064
53. 2100 Pharmaceuticals, medicinal chemicals, etc.	CHE	H	3	0.844
54. 2211 Rubber tyres and tubes	RUB	M	3	0.909
55. 2219 Other rubber products	RUB	M	3	0.939
56. 2220 Plastics products	RUB	M	3	0.926
57. 2310 Glass and glass products	MET	M	6	0.956
58. 2391 Refractory products	MET	M	6	0.954
59. 2392 Clay building materials	MET	M	6	1.007
60. 2393 Other porcelain and ceramic products	MET	M	6	0.910
61. 2394 Cement, lime and plaster	MET	M	6	1.058
62. 2395 Articles of concrete, cement and plaster	MET	M	6	0.984
63. 2396 Cutting, shaping and finishing of stone	MET	M	6	0.992
64. 2399 Other non-metallic mineral products n.e.c.	MET	M	6	0.988
65. 2410 Basic iron and steel	MET	M	6	1.009
66. 2420 Basic precious and other non-ferrous metals	MET	M	6	0.986
67. 2431 Casting of iron and steel	MET	M	6	0.874
68. 2511 Structural metal products	MET	ML	3	0.841
69. 2512 Tanks, reservoirs and containers of metal	MET	ML	3	0.909
70. 2513 Steam generators, excl. hot water boilers	MET	ML	3	0.960
71. 2593 Cutlery, hand tools and general hardware	MET	ML	3	0.861
72. 2599 Other fabricated metal products n.e.c.	MET	ML	3	0.910
73. 2610 Electronic components and boards	SCI	H	3	0.833
74. 2620 Computers and peripheral equipment	SCI	H	3	0.878
75. 2630 Communication equipment	SCI	H	3	0.769
76. 2640 Consumer electronics	SCI	H	3	0.834
77. 2651 Measuring/testing/navigating equipment, etc.	SCI	H	3	0.823

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Table 15 – *Continued from previous page*

Manufacturing industry (4-digit class of ISIC Rev.4)	Sectoral group	R&D group	Elasticity of substitution	Elasticity of demand
78. 2652 Watches and clocks	SCI	H	3	0.847
79. 2660 Irradiation/electromedical equipment, etc.	SCI	H	3	0.777
80. 2670 Optical instruments and photographic equipment	SCI	H	3	0.716
81. 2710 Electric motors, generators, transformers, etc.	ELE	MH	3	0.783
82. 2720 Batteries and accumulators	ELE	MH	3	0.872
83. 2731 Fibre optic cables	ELE	MH	6	0.907
84. 2732 Other electronic and electric wires and cables	ELE	MH	6	0.835
85. 2733 Wiring devices	ELE	MH	6	0.652
86. 2740 Electric lighting equipment	ELE	MH	6	0.875
87. 2750 Domestic appliances	ELE	MH	3	0.928
88. 2790 Other electrical equipment	ELE	MH	3	0.849
89. 2811 Engines/turbines, excl. aircraft, vehicle engines	MACH	MH	3	1.000
90. 2812 Fluid power equipment	MACH	MH	3	1.005
91. 2813 Other pumps, compressors, taps and valves	MACH	MH	3	0.831
92. 2814 Bearings, gears, gearing and driving elements	MACH	MH	3	0.965
93. 2815 Ovens, furnaces and furnace burners	MACH	MH	3	0.894
94. 2816 Lifting and handling equipment	MACH	MH	3	0.813
95. 2817 Office machinery, excl. computers, etc.	MACH	MH	3	0.698
96. 2818 Power-driven hand tools	MACH	MH	3	0.906
97. 2819 Other general-purpose machinery	MACH	MH	3	0.894
98. 2821 Agricultural and forestry machinery	MACH	MH	3	0.795
99. 2822 Metal-forming machinery and machine tools	MACH	MH	3	0.765
100. 2823 Machinery for metallurgy	MACH	MH	3	0.920
101. 2824 Mining, quarrying and construction machinery	MACH	MH	3	0.765
102. 2825 Food/beverage/tobacco processing machinery	MACH	MH	3	0.820
103. 2826 Textile/apparel/leather production machinery	MACH	MH	3	0.865
104. 2829 Other special-purpose machinery	MACH	MH	3	0.798
105. 2910 Motor vehicles	TRA	MH	3	0.877
106. 2920 Automobile bodies, trailers and semi-trailers	TRA	MH	3	0.810
107. 2930 Parts and accessories for motor vehicles	TRA	MH	3	0.911
108. 3011 Building of ships and floating structures	TRA	M	3	0.829
109. 3012 Building of pleasure and sporting boats	TRA	M	3	0.624
110. 3020 Railway locomotives and rolling stock	TRA	MH	3	0.891
111. 3030 Air and spacecraft and related machinery	TRA	H	3	0.707
112. 3091 Motorcycles	TRA	MH	3	0.839
113. 3092 Bicycles and invalid carriages	TRA	MH	3	0.844
114. 3099 Other transport equipment n.e.c.	TRA	MH	3	0.670
115. 3100 Furniture	OTH	ML	3	0.882

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Manufacturing industry (4-digit class of ISIC Rev.4)	**Sectoral group**	**R&D group**	**Elasticity of substitution**	**Elasticity of demand**
116. 3211 Jewellery and related articles	OTH	M	3	0.773
117. 3212 Imitation jewellery and related articles	OTH	M	6	0.742
118. 3220 Musical instruments	OTH	M	3	0.796
119. 3230 Sports goods	OTH	M	3	0.880
120. 3240 Games and toys	OTH	M	3	0.899
121. 3250 Medical and dental instruments and supplies	OTH	MH	3	0.750
122. 3290 Other manufacturing n.e.c	OTH	M	3	0.922

Note: Allocation to 11 sectoral groups is based on authors' own categorisation. Allocation to R&D groups is based on the OECD Taxonomy of Economic Activities based on R&D Intensity. The value of elasticity of substitution between different varieties of the same product is set at 3 for those industries that largely manufacture differentiated and at 6 for those industries that manufacture homogenous goods. Allocation of manufacturing industries into those that produce differentiated and homogenous goods is based on authors' own categorisation. The value of elasticity of demand is derived from Ghodsi et al. (2016b). List of abbreviations: a) Sectoral group: CHE = Chemicals and pharmaceuticals; ELE = Electrical; FOOD = Food processing; MACH = Machinery; MET = Metals and non-metallic minerals; NC = Not classified; OTH = Other; RUB = Rubber and plastic; SCI = Electronic and scientific; TEX = Textiles, apparel and footwear; TRA = Transport; WOOD = Wood, paper and printing; b) R&D group: H = High R&D; MH = Medium-high R&D; M = Medium R&D; ML = Medium-low R&D.

B Modelling demand for and supply of differentiated products

The three models used in the projections in this paper use variants of a two-stage Dixit-Stiglitz constant elasticity of substitution demand system for differentiated products. As is noted in the paper, the model is a partial equilibrium model in which each of the sectors is treated as independent of the others.

Overall demand for the sector's product in a particular national market is represented by the output index X, which is assumed to be a constant elasticity of substitution (CES) function of the sales of different varieties of the product, x_i:

$$X = \left(\sum_{i=1}^{n} a_i^{\frac{1}{\sigma}} x_i^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}} \tag{1}$$

where the individual x_i represent the quantities of the different varieties of the good, the ai are parameters which sum to 1, and X is the quantity index that aggregates the different varieties.

If variety i is sold at price p_i, it can be shown that the demand functions for individual varieties are given by

$$\frac{x_i}{X} = a_i\left(\frac{p_i}{P}\right)^{-\sigma} \tag{2}$$

where *P* is the price index for the product given by the CES function

$$P = \left(\sum_{i=1}^{n} a_i p_i^{1-\sigma}\right)^{\frac{1}{1-\sigma}} \tag{3}$$

which measures the aggregate cost of the goods which constitute *X*, so the value of total spending in this market is

$$\sum_{i=1}^{n} p_i x_i = PX \tag{4}$$

If it is assumed that overall demand X is a constant elasticity function of the price index P with elasticity $-\mu$, then the own-price and cross-price elasticities of demand can be derived from (2) and (3) as

$$\epsilon_{ii} = -\sigma + (\sigma - \eta)s_i \tag{5}$$

$$\epsilon_{ji} = (\sigma - \eta)s_i \tag{6}$$

where $s_i = p_i x_i / PX$ is the share of variety i in sales of the product in this market, noting that, because cross-price effects enter only through the price index, the cross-price elasticity depends on the market share of the variety whose price is changing, not on the characteristics of the product whose demand is changing as a result.

B.1. The Armington model

In the first model using this structure, we suppose that goods are differentiated only by country of origin and are sold in perfectly competitive markets. With four countries in our model, there are four varieties of the product sold in each of the four national markets. Price is equal to marginal cost, and we assume that there are decreasing returns on a market-by-market basis: marginal cost in each market rises with sales in that market but is unaffected by sales in other markets. The decreasing returns are at a mild rate: the assumed elasticity of supply is high. In each country market, (5) relates the elasticity of demand for imports from each country source (and for the home-produced variety) to the underlying elasticities and to market shares. It is easily seen that the same equation gives the overall elasticity of import demand; that is, the response to an equiproportionate increase in all import prices is given by (5) where the share is the market share of all imports.

B.2. Imperfect competition

In this version of the model, products are differentiated by producing firm, so firms have some market power. Now (5) determines the elasticity which enters firms' pricing decisions. However, the relationship needs careful interpretation. Even though we are working with a somewhat disaggregated classification of manufactures, from the perspective of competition between product varieties the classification is too aggregate: a typical sector should be thought of as consisting of several sub-sectors each of which produces a distinct set of product varieties.

Applying the partial equilibrium approach at the sub-sector level, the market share relevant to the firm's elasticity of demand is the firm's market share in the relevant sub-sector. If the sub-sectors are symmetric, then s_i, the share of firms from country i will be the same for each sub-sector, but from the perspective of the individual firm, the it is its market share in the sub-sector that is relevant to its pricing decision, so in (5) s_i is replaced by s_i/n_i, where n_i is the number of (equal-sized) firms operating in the sub-sector.

(i) In the first version of the imperfect competition model, we assume that firms have constant marginal cost, so the only source of economies of scale comes from the spreading of fixed cost over a larger output.

(ii) In the second version, the one used to generate the main results in the paper, we assume that firms' marginal cost decreases with output, so there is a second source of scale economies. This gives rise to a multi-market linkage: if a firm expands its sales in one market, its marginal cost falls and therefore in all other markets its price falls and its sales expand.